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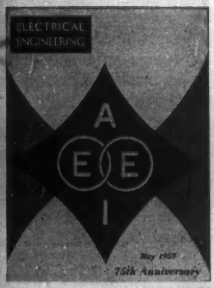
75 Years —
A Prologue to the Future



THE COVER: Using the AIEE emblem, Remo Cosentino (staff editor—artist) designed the cover to commemorate the Institute's Diamond Jubilee.

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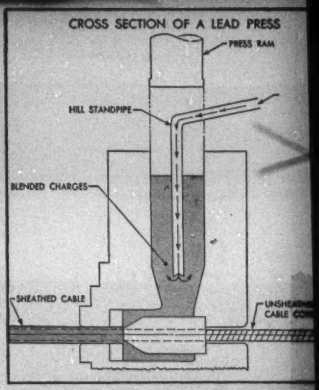
Thorough Blending of Successive Lead Press Charges is Essential to Manufacturing Structurally Sound Paper Cable Sheaths

N. A. Zamborsky
Manager-Process Engineering

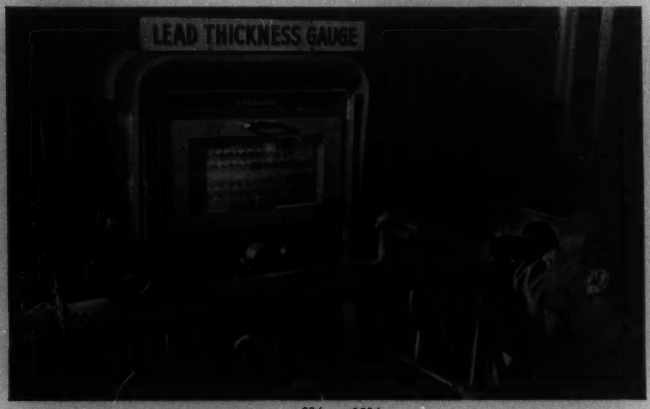
The Stabilized Lead used in the manufacture of Okonite paper cable sheaths is fed into lead presses by Okonite's Hill Standpipe Method. This permits successive charges to be fed into the press by "bottom-filling and mixing" —blending in *from beneath* the surface of the charge that is being extruded. It assures uniform knitting together of lead charges . . . essential to the manufacture of structurally sound sheaths. It prevents the manufacture of structurally inferior sheaths . . . sheaths that are prone to crack because defects have actually been manufactured into them. These defects occur when successive lead charges do not blend together properly.



While the operator is skillfully agitating th Hill Standpipe, a new charge of molten Sta bilized Lead flows through the Hill Standpip into the press. Consequently, not only doe the filling take place from under the surface o the previous charge, but the new charge is also thoroughly blended with the previous one

Ultrasonics are Making a Significant Contribution to the Manufacture of Reliable Cable Sheaths

Thin, weak areas in a cable's sheath are a common source of paper cable failures. These "thin spots" are caused by inadequate control of the lead sheathing operation. In 1941, Okonite engineers introduced a new electronic technique for the control of this procedure. It was called the Electronic Uniformity Gauge. The latest revision of the uniformity gauge employs ultrasonic resonance waves to measure the thickness of the sheath being manufactured. These measurements, accurate to 1/1000th of an inch, are then projected on a cathode tube where they can be observed by the press operator. Consequently, an Okonite lead press operator is able to keep a constant check on the thickness of the sheath his press is extruding. As a result, Okonite paper cable sheaths average only 3% variation in thickness. AEIC specifications, depending on the situation, allow a maximum variation of 10%. Okonite, however, self-imposes a maximum 7% variation in all cases. Quite a difference. In other words, Okonite paper cable sheaths *on the average* are 3⅓ times more uniform than the industry specifications require and *are always* nearly 1½ times more uniform than these specifications require.



. . . 3% vs. 10%

1. The Hill Standpipe Method and
2. the Electronic Uniformity gauge . .

. . . two concrete examples of the devoted ingenuity that Okonite applies to the manufacture of paper cables. This is all evidence to the fact that Okonite paper cables contain *added values*, values that are not written into specifications.

Today, every good engineer I know is seeking ways to get the maximum value out of the money he invests for his company or client. The *added values* in Okonite paper cables provide an opportunity to get extra life and dependability out of electrical cable systems. As one engineer to another, I urge you to become better acquainted with the long range economy of Okonite paper cables.

If you have not received your copy of the new Okonite paper cable catalog, or if I can be of help to you with a current problem, please get in touch with me at The Okonite Company, Passaic, New Jersey.

6041

where there's electrical power . . . there's **OKONITE CABLE**

For more information circle 1 on reader service card.

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When Ohio Power makes EHV

First major step in the integration of the American Electric Power System (then American Gas and Electric) occurred in 1917, in the territory of what is now the Ohio Power Company.

The modern 30,000-kw Windsor steam plant had just been built on the Ohio River near Wheeling. The plant was 55 miles from its load center at Canton, Ohio. Here was the foundation for an integrated system, with generation located for maximum efficiency, tied together by high-voltage transmission lines.

132-kv transmission was an extra-high voltage in its day. Success of the Windsor-Canton line quickly led to more 132-kv transmission in both Ohio Power and sister AEP companies. By 1929, the 132-kv network permitted two-way power exchange throughout the area from Lake Michigan to the border of North Carolina.

Now American Electric Power has 1,200 miles of 345-kv transmission line, today's

Courtesy Blackstone Studios

A Salute to the American Institute of Electrical Engineers

An anniversary is a truly happy event when the promise of the future outweighs the accomplishment of the past. In this respect, AIEE is particularly fortunate.

Our Diamond Anniversary comes at the start of an age in which the need for those in our profession is greater than it has ever been. It is a time of looking forward, of renewed respect for man's skills and determination to develop his intellectual potential.

Specialization is the order of the day, so the Institute has opened new avenues of expression for the specialist through expanded technical committee structure, technical conferences on a single subject, availability of all papers individually, transactions published bimonthly by divisions as well as annually.

As specialization increases, so does the need for intercommunication among specialists. Because it embraces the entire range of electrical engineering subjects, AIEE is uniquely qualified to fill this need.

With our sister Founder Societies, we look ahead to the breaking of ground for our new home, the United Engineering Center overlooking United Nations Plaza in New York. Cooperation among the Societies in matters of mutual interest is steadily increasing.

The Institute's organization has been continually under study. None of those proposing revision has had his plan wholly adopted. We have seen demonstrated a healthy ability to compromise, and the courage to implement changes when improvement is foreseen. Such characteristics bespeak vigor and flexibility, and show AIEE ready for the period of fast technological development ahead.

And now, if I may be permitted a word about my personal experience, which I am sure I share with many others who have been privileged to serve as officers of the Institute: Since college days, the Institute has taken always some, sometimes all, of my free hours. In return, it has been a continuous source of pride as well as of information. It has provided enjoyment in the company of colleagues. (Our founding fathers wisely listed "social intercourse" as the foremost method by which the Institute might accomplish its objectives.) It has given me a voice in the affairs of my profession. I am grateful.

So it is with warm regard that I wish all of you—for you as its members *are* the Institute and therefore the celebrants—a very happy 75th Anniversary on May 13, 1959.

L. F. Hickernell
President
American Institute of Electrical Engineers

75 Years—
A Prologue to the Future

Preface

ON MAY 13, just 75 years ago, a group of men interested in electricity, many of whom were telegraph electricians, founded the AIEE. The objectives then were much the same as they are today—namely to hold meetings, to read and discuss professional papers, and to circulate the information by means of publication, as well as to promote "social intercourse." Today, the organization is comprised of over 45,000 members, 10,000 students, and 56 technical committees with several hundred subcommittees in six broad technical divisions. In passing, it is interesting to note that in the Institute's first paper, "Notes on Phenomena in Incandescent Lamps" by Professor Edwin J. Huston, attention was focused on the high-vacuum phenomena observed by Mr. Edison in incandescent lamps and known as "the Edison effect," which was a forerunner of the great electronic industry of today.

As the technical progress of the first 50 years was well recorded in the 50th Anniversary issue, a group of experts was invited to review the progress of the past 25 years for this 75th Anniversary issue and forecast the future insofar as possible.

THE SUBJECT MATTER has been conveniently arranged in four broad divisions—Basic Sciences, Communications, Industry and Applications, and Electric Power.

No one will dispute that the great scientific discovery of the past quarter century was nuclear fission. The Shippingport facility went critical on December 2, 1957, and reached full power output of 60,000 kw within 3 weeks. A number of other large plants are under construction with several different types of reactors under the AEC power demonstration reactor program. The famed exploits of the *USS Nautilus* are well known.

Accelerated research during World War II brought to focus the great value of research as evidenced by the billions now being spent by Government and industry. The scientists, physicists, chemists, and research workers brought forth an abundance of new materials and opened whole new areas of exploration, particularly in solid-state physics, and molecular structure of matter.

Consider but one great development: television broadcasting on a nation-wide network which now is taken as a commonplace matter. Yet back of this accomplishment was the experience gained with radar in World War II, exhaustive research on the iconoscope, invention of the image orthicon camera, research on luminescent materials, the transcontinental microwave-radio relay, and coaxial cable.

The postwar era saw the invention of the transistor. This tiny solid-state device, with the ability of a small input to control a large output and perform amplifying, oscillating, and detecting functions, led to a whole series of semiconductors and solid-state devices, which together with printed circuits, the ferrite series, and subminiature tubes extended miniaturization.

Perhaps the most spectacular breakthrough has been the placing of satellites and man-made planets in orbit during the past 19 months. Aside from the propulsion problems, these feats involve a whole series of electrical problems for instrumentation, control, guidance, and telemetry, as well as the necessity of high-speed computers to process large amounts of tracking data. Pioneer IV, launched on March 4, 1959, with a payload weight of only 13.4 pounds, was tracked by the Goldstone Station to a distance of approximately 407,000 miles before its signal was lost due to expiration of battery power, representing the greatest distance over which an intelligible signal has ever been transmitted.

DURING THE PAST 25 YEARS, the electric power industry has shown remarkable growth with power generation expanding well over 700% or at a rate almost 2½ times as fast as the increase in the gross national product. Notable are the greatly increased sizes of units brought about through improved designs, new insulating materials, the silicones, plastics, polyethylene, grain-oriented steels, hydrogen cooling, inner cooling of rotor and stator, as well as the employment of supercritical pressures. All of these, in conjunction with higher speed relays and circuit breakers, add up to improved efficiencies and greater reliability, with dimensions and weights of units decreased. In the air- and marine-transportation fields, much the same story applies except that higher frequencies have been used to reduce sizes and weights of generators and new materials and improved designs withstand greater accelerations and are more environment-free.

The speeds of computers have been greatly increased and designed more compactly through employment of electronic circuits, transistors, semiconductor devices, ferrites, and improved methods of memory storage. Computers have come into use for automatic load dispatching on power systems and several hundred design and operational problems have been programmed. A much greater impact of computers in connection with automation in industry is expected in the years ahead. Another promising possibility is direct conversion of heat into electricity.

In presenting the progress of the past 25 years, no attempt was made to obtain world-wide developments but many of the authors have referred to foreign developments, some of which are equal to or excel those in the United States. However, the articles presented probably represent the greatest collection of authoritative material in the electrical–electronic industries ever assembled under one cover. The efforts of the authors and their assistants, who unselfishly devoted many hours of search and compilation in preparing the contributions, are gratefully acknowledged.

The Editor

Basic and Applied Engineering Research

C. GUY SUITS
FELLOW AIEE

PAUSING to look back over your shoulder at the last quarter century is an interesting experience, but it is also a little unsettling. If you start with recent copies of *Electrical Engineering*, for example, and gradually work your way back into the past, you find some strange sensations sifting out from between the pages of the big bound volumes. As you move back through the 40's, into the 30's, you find yourself in a world in which men are asking themselves, with some anxiety, how the Nation can best lift itself out of the Depression . . . where engineers are properly impressed with the complex electrical system of a twin-engined *DC-3* . . . and where the floodlit buildings of the great World's Fairs, glowing with exotic colors, seem dedicated to a search for light-hearted amusement.

When we have lingered for a while in such an age—half-reliving it, seeing the surface of events without feeling the urgencies that then were part of them—we begin to feel something like nostalgia. If we could go "home" to such a time, we muse, problems would pose no threats, and we could move through such a simple world as confidently as a boy moves through the rooms of a familiar house.

Fortunately for the preservation of our illusions, "you can't go home again," as Thomas Wolfe once reminded us. Indeed, from time to time in the old pages we find signs that the past bore some disconcerting resemblances to the present. Here is an item about the probable duration of a shortage of young engineers; here is another citing large Soviet expenditures for research. Things may not have changed so much after all.

It would seem at first sight to be self evident that from this point of vantage the outstanding scientific developments of the last 25 years could be readily identified. But as I consider some of these developments, I am not so sure. Such staggering developments as nuclear fission, of course, come to the forefront in any such appraisal. But even in this case, are we sure now of the area of greatest importance of this discovery? Will it, for example, be in biology and medicine, or in the technology of power generation? In either case, how would you compare the discovery of fission with the less spectacular but tremendous advances in our knowledge of the structure of matter, and especially the solid state? How about fusion, with its almost overwhelming possibilities, but equally awe-inspiring difficulties? In spite of all of these questions, however, there can be no doubt that the discovery of nuclear fission has left a fundamental impact on this 25-year period. The chain of developments in this field, with its mixture of tragedy and promise, is more properly the province of the articles in this issue that deal with military affairs and reactor technology, but we note it here as an outstanding example of a modern phenomena; a development in science that affects the lives and times of people everywhere.

The fusion reaction is still a promise for the future, for the technical feasibility of thermonuclear power generation has not yet been proved. Many organizations, including my own, are working on this problem, and

Giant bank of capacitors being assembled at GE Research Laboratory to produce large amounts of energy in short "bursts" for fusion research program. It was announced in June 1957 that GE scientists were seeking safe and inexpensive power from the hydrogen bomb fundamental process. Leading the GE fusion work is Dr. Henry Hurwitz (*right*), discussing instrumentation of project with Dr. W. F. Westendorp, who designed much of the experimental equipment required.

are determined to convert this cosmic dream to practical reality. Perhaps by the time the next 25-year review is published we will be reading an article on how fusion was successfully brought to fruition as an economic power source. Between that story and this one, however, much basic work will have to be done, and many dollars will have been allocated to research-and-development budgets.

Semiconductor devices constitute another potent force

Dr. C. Guy Suits is vice-president and director of research, General Electric Co., Knolls Atomic Power Laboratory, Schenectady, N. Y.

for change. These have been absorbed into the mainstream of our technology more readily than the technology "fission products" that resulted from nuclear physics. Research in this area has given new impetus to the study of solid-state physics, at the same time that it has introduced a variety of devices that have been accepted at a phenomenal rate by the men responsible for designing and manufacturing products. Certainly, we have seen few cases of a laboratory product winning such rapid acceptance on a grand scale. When *Electrical Engineering* printed its first report on the birth of the transistor at the Bell Telephone Laboratories in the August 1948 issue, that device was still an infant; its cost unknown, its potential largely unpredictable. The story ran to only three-quarters of a page. By 1958, the dollar volume of sales in transistors and diodes had passed the $200 million mark. My esteemed colleague, Mervin Kelly of Bell Telephone Laboratories, estimated not long ago that by 1965 this sales figure would reach $500 million. By then, this phenomenal youngster will be only 17 years old—a rather prosperous adolescent. Here again is a field where progress has resulted from the close study of what goes on inside matter: the subtle interactions that make the microcosm as fascinating a world as the macrocosm.

ELECTRON TUBES

SINCE THE REVOLUTIONARY DEVELOPMENT of the transistor, there has been a tendency in some quarters to assume that the vacuum tube is a dead duck. Even more thoughtful persons have expressed concern that research and development on vacuum tubes might become neglected in favor of semiconductor research. But the remarkable achievements attained in the field of vacuum tubes in recent years show that the vacuum-tube art is far from dead.

High-frequency transistors were first made at the GE Research Laboratory with equipment shown. Developer of process was Dr. R. N. Hall (left), who devised method of growing tiny crystal "hearts" of transistors from thin silicon wires. At right is GE scientist R. I. Scace. Transistors made with "meltback" process can be used in television, radar, shortwave radio, and other electronic devices where high-frequency requirements previously called for bulkier vacuum tubes.

Not long ago, there was announced a new type of metal-and-ceramic tube that may usher electronics into a new era. These microminiature tubes, some no larger than a shirt button, resemble stacks of metal and ceramic disks piled one atop the other. The bulky and often fragile envelopes in which electron tubes were once built has here been replaced by a compact and rugged case. Their construction enables them to be operated in temperatures at which conventional tubes would melt down into shapeless puddles. When these tubes are operated at such temperatures, the heater element becomes unnecessary, making the tube even more compact. The radical electronic concepts incorporated in these tubes and their associated components and circuits deserve the term "the new electronics," and constitute an authentic breakthrough in an old science. The advantages that they offer in size, weight, temperature and radiation tolerance, and electronic performance will be especially significant in future missile, aircraft, and space technology.

These recent tube developments were based upon foundations established during World War II, when a so-called "lighthouse" tube was developed for applications at microwave frequencies. These lighthouse tubes were particularly applied to improved receivers to extend the range of early-warning radar stations. The lighthouse tube, in turn, was a descendent of the early electronic tubes that first (in the mid-30's) brought the advantages of a metal envelope, rather than a glass one, to receiving tubes.

Other innovations in tube design brought many new types of electronic devices from the laboratory to the market place during these years. To choose only one example, the magnetron has become famous for its extensive use in all types of radar equipment. This electron tube was of inestimable value in wartime radar because of its ability to generate efficiently very high levels of pulsed microwave power. As a continuous-wave generator it was also utilized in countermeasures, successfully employed in jamming enemy radar. The story of its use in this connection can properly be left to those who are reviewing military developments, but it should be noted that the magnetron was not limited to its defense uses. Since the war, magnetrons have assumed a central role in a new peacetime industry, microwave dielectric heating. One phase of this field is the area of electronic cooking, which may well hold promise of great development in the years ahead.

ELECTRON IRRADIATION

IN OTHER FIELDS, too, the interest of the research scientist in the subtleties of matter has brought results. Our growing knowledge of polymer chemistry has taken us deep into the realm of molecular behavior, with results that are bound to have (and indeed already have had) great importance for the electrical industry. To cite only

Progress in electronics is illustrated (above) by comparison of three devices capable of serving same purpose. At left, electronic tube with glass envelope; at right, between fingertips, a transistor; and in the center, on pedestal, a new metal and ceramic electron tube are shown.

Vacuum tube, center top (GE laboratory model of 6BY4 microminiature ceramic tube), operates —as indicated by oscilloscope pattern—even when red-hot in blowtorch flame. September 1956 development.

Miniature metal-and-ceramic electron tube, above, is about shirt-button size and compares favorably with transistor (*right*). Tube is one of series developed at GE Research Laboratory in recent years.

Revolutionary new tiny microminiature ceramic vacuum tube (at left) is held by J. E. Beggs, GE scientist who developed it with associates.

one example, it was discovered that polyethylene could withstand higher temperatures without softening if it was irradiated with an electron beam. It was then discovered that adding what is erroneously called a "filler," such as lampblack, in conjunction with the irradiation, further improved its characteristics. The combination of the two processes proved to be more satisfactory than either alone. Although a high-grade, unfilled, and unirradiated polyethylene melts before it reaches a temperature of 300 F, a comparable filled and irradiated polyethylene can support more than 500 pounds per square inch at this temperature. I indicate that the term "filler" is a common misnomer in this case, because a solid-polymer chemical reaction is important to the result; the "filler" is thus much more than a diluent.

The changes that are produced in polyethylene (and many other substances) when they are irradiated by means of an electron beam are the result of the action of high-energy electrons. These convert the material into its new form by knocking out a few hydrogen atoms from each molecule of the polymer, thus setting up carbon-to-carbon bonds between adjacent molecules. This produces "cross-linking," or vulcanization of the polyethylene. It is as if the long-chain molecules had locked arms to give themselves more stability in warding off the attack of heat and chemicals. Perhaps the experimental electron irradiation of food is the subject in this field about which we have heard the most. Experiments have shown that foods can be sterilized by means of electron beams and can then be kept for much longer periods of time "on the shelf." Various problems have presented themselves, however, including the undesirable colors and odors that are produced in some cases, but progress in this field has been encouraging enough to prompt the U. S. Army Quartermaster Corps to go ahead with plans for large-scale processing of food. It may be that some harmless deviations from normal flavor, which would be unacceptable to a housewife, will prove to be acceptable to the "captive audience" in a military mess hall.

IMPROVED MATERIALS

MANY NEW DEVICES and improvements in old ones have been made possible by improvements in the materials with which we work. The creation in the laboratory of the silicones during the last 25 years made available to the electrical engineer a greatly improved class of materials. When used as insulation in motors, their resistance to high temperatures permits the motor to be run hotter, increasing its capacity. Their other uses, ranging from mold-release agents in casting to cleaning tissues for eye-glasses, include a remarkable variety of applications.

In this case, as is so often true, hindsight proved to be much more efficient than foresight. In 1937, with our favorite quarter-century barely under way, one of the pioneers in the field reportedly said, "Since the few [silicones] which are known are very limited in their reactions, the prospect of any immediate and important advance in this section of chemistry does not seem hope-

Boiled in oil, these two O-rings were same size when immersed in jar of boiling (350 F) *JP-4* jet engine fuel. One of them, made of GE's nitrile silicone rubber, kept its size and shape. The other, made of ordinary silicone rubber, has swollen to nearly twice its original size. Nitrile silicone rubber is described as "a major advance in chemistry that will offer industry—particularly automotive and aircraft—a unique combination of important properties never before available in a single material."

Reduced loss is noted in experimental transformer made with GE's "four-square" magnetic sheet material when compared with transformer identical in all respects except that it is made from the best magnetic sheet now in use—a singly oriented material announced in November 1957. J. L. Walter marks where loss-indicating needle registered when ordinary "good" transformer (*right*) was tested. Transformer incorporating new material (*left*) was being tested when photograph was taken. Observing is Dr. W. R. Hibbard, Jr., manager of alloy studies at the GE Research Laboratory, who collaborated in original conception of doubly oriented "four square" magnetic sheet.

ful." Last year, the silicone industry sales were estimated to be $50 million, and they are growing rapidly.

New strides in our increased understanding of metals, and in particular of magnetic materials, may prove to be of great significance, since there is a great deal still to be learned in this area. One development that has already come to light is doubly oriented magnetic iron. In this material, the directions of easy magnetization have been arranged so that a square path can be followed by the lines of magnetic force. Previously it was possible for an oriented material to be easily magnetized in a single direction. The new material makes it possible for two directions of easy magnetization to be established at right angles to each other. Lower energy losses and reduced noise in many types of electrical equipment can be expected when commercial production is achieved with this material (named "four-square" or "cubex," depending on whose advertising you are reading).

One of the most interesting devices that has appeared on the technical horizon in recent years is the maser. This acronym stands for Microwave Amplification by Stimulated Emission of Radiation. The device designated by that imposing title has brought us extremely interesting developments in amplification and oscillation. One of the defects of conventional amplifiers, of course, is that they contribute a certain amount of noise to the output. The maser is not subject to this limitation and is consequently capable of detecting extremely weak signals, such as, in the case of radio telescopes, those emanating from outer space. It amplifies an incoming signal by drawing off energy that had

New materials have been produced, and more can be expected, as a result of studies of electron irradiation effect. Electron-beam generator (a modified X-ray machine) is used to irradiate polyethylene tape. Physicist E. J. Lawton checks operation of equipment.

Thermionic converter (above), high-vacuum type, is heated by torch. Current produced runs small motor that spins "pinwheel."

Electricity generated directly from heat operates light bulb lighting face of Dr. V. C. Wilson (center, above.)

High-vacuum thermionic converter, made of metal and ceramic, is size of a quarter. Development was announced in June 1958.

Dr. Wilson, inventor of thermionic converter, which changes more than 8% of applied heat energy into electric power, (right) inspects an experimental thermionic converter, announced in November 1957. The GE scientist's invention is considered a significant step toward solution of one of the age-old riddles of the electrical industry.

previously been stored, by one means or another, within its atoms (or molecules). Some of the original masers made use of energy released from molecules of gaseous ammonia; more recently developed solid-state masers use crystals of silicon, quartz, or synthetic rubies.

Work at temperatures close to absolute zero has implications for tomorrow's technology that at best can be only dimly foreseen at the present time. Low-temperature phenomena, once mere curiosities, have lately been enjoying an upsurge of interest. This is, in part, a result of the successful development after World War II, of a simple machine for liquefying helium, a change of state that takes place at 4.2 degrees Kelvin. In and about this strange region, liquid helium possesses the ability to run uphill, climbing up and over the sides of a container; certain substances display marked variations from normal in their thermal conductivity; and, in many metals, alloys, and compounds, electrical resistance disappears completely. However, the use of loss-free transmission lines will have to be deferred, because we are faced with (among other considerations) the problem of maintaining such lines close to —459.6 F, an ambient temperature that is seldom found in the open air, even in our newest state, Alaska. It seems safe to say that the prospects for such well-chilled transmission lines are not as bright as those of other devices that depend on low-temperature phenomena, such as the cryotron, a minute on-or-off switching device that may find applications in computers.

The satellites that are criss-crossing the sky in increasing numbers have heightened interest in unusual types of power sources. There has been investigation and some development work done on such items as sources powered by radioactivity, solar batteries, and devices called thermionic converters, which convert heat directly into electricity without moving parts. Although none of these devices are as yet at a stage where they will challenge the supremacy of conventional turbine–generators for producing large quantities of power, they may well prove valuable in special situations, where a small amount of power is needed, or where a very lightweight generator is required, regardless of the economics of the operation.

The "thermionic converter," for example, has been developed to the point where its efficiency is of the order of 10% (as contrasted with the turbine–generator's 34%). In this device, when the cathode is heated to a high temperature, electrons are boiled out of its surface and travel through an intervening space to a relatively cool anode. From this point, they can be sent through an external circuit and perform work. The presence of a partly ionized gas, or the use of extremely close spacing in a high vacuum, offsets the space-charge effect.

Equally interesting, in recent years, was the achievement of a long-sought goal—the direct amplification of light without the use of electron tubes. In demonstrations of the "light amplifier," an ultraviolet or blue image is projected upon a simple phosphor screen,

Using ordinary lantern-slide projector, D. A. Cusano, GE scientist who created first direct light-amplifying phosphor, demonstrates his device. Dim ultraviolet image projected on 4-inch experimental screen is brightened by using current from dry-cell batteries to create an electric field across special phosphor surface. Because amplification is nearly proportional, over-all contrast of projected image remains unchanged and brightening occurs. Measurements show that for each photon of light projected on screen, up to 10 are given off.

which is connected to a power source. When voltage is applied to the screen, it emits up to 10 times as much light as was projected upon it. In effect, the brightness of the visible image can be controlled by "turning up the screen," rather than turning up the projector. Light amplification occurs in this device only when there is both incident light *and* a voltage applied to the phosphor screen; neither is sufficient by itself. The light amplifier is one aspect of intensive research into electroluminescence, a field which is promising to give us significant developments both in the field of illumination and possibly in new types of viewing screens for television.

THE FUTURE

As far as predictions of the future are concerned, the research scientist is in a rather unusual position. He is often credited with more ability in the field of prognostication than is really due him, because he can apparently predict the technology of the next few years with a considerable degree of accuracy. In truth, however, this new technology is based on science that is already an accomplished fact in the laboratories. Since the average discovery takes somewhere between 5 and 10 years to make its way from the laboratory to the market place, it is evident that the scientist in 1959 is in a good position to estimate the technology which engineers will be designing into products in 1969 without straining his prophetic powers very much.

This is not to imply, of course, that he can predict lightheartedly the exact form that particular products will take within that span of years. The vagaries of economics may make a product extremely desirable or completely unmarketable for reasons which have nothing to do with its technical feasibility. By the same token, the features and general complexion of a product or line of products may be determined to a large extent by public preferences that again have nothing to do with technology. If the American automobile industry, for example, finds itself launched on a trend toward more compact cars for the next few years, it will not have any discernable relationship with our technical ability to build bigger or smaller cars.

Nevertheless, we can with some assurance say a few things about our probable future. One thing we can expect is that in the next decade we will see even more electronic devices than we have in the past. This field, which has had such a phenomenal growth during the last quarter century, is still picking up speed and there is no sign that it has yet reached its maximum velocity. Electronics will be very much with us, not only in the factory, but also in the office, in the home, and on the farm. Electronic cooking certainly seems to be one of the aspects that we can anticipate with confidence.

Certainly, the recent concern with automation forecasts an explosive development of electronics in industry. It is hardly a matter for debate as to whether automation and its key electronics should or should not be applied to industry, since it appears to be an absolute necessity. There will simply not be enough workers to manufacture all the things we will need if they attempt to do so by present methods. It has been estimated that we must produce at least 50% more goods and services by 8 or 10 years from now and we will have to do it with only about 10% more human effort. If there is any alternative to automation, it is certainly not apparent at this time, assuming that we do not plan to make drastic cuts in our standard of living, and I think that is a safe assumption.

There likewise seems no doubt that in this vast electronics wonderland semiconductors will have a very prominent role indeed. We will no doubt wonder how we ever got along without automation in our factories by 10 years from now, and it will probably be just as true that in electronics we will wonder how we managed without all of the semiconductor devices that will be available in profusion by then.

But the future will be more than merely automated factories and semiconductors. Chemistry is being reshaped to a significant extent by discoveries in polymers and in other fields. As we have noted already, electron irradiation has been applied to the problems of altering the properties and structures of certain chemical substances. Today, chemicals are manufactured mainly by the controlled application of heat, pressure, and catalysts. Electron irradiation now presents itself as a new means of promoting chemical reactions. Just as conventional chemical reactions gave us, during the past quarter century, a host of substances that were previously unknown, so we can anticipate that within the next 25 years the applications of electron irradiation in the field of chemistry will provide us with still another catalog full of new and specifically useful materials. In more traditional chemical respects, also,

the mighty polymers are undergoing some basic changes that are going to expand their usefulness vastly in the years immediately ahead. We will find them in the most unexpected places, frequently instead of metals.

Another area in which we can expect to see considerable advances is the study of the mechanical properties of crystalline solids. As previously noted, concern with the structure of solids and its effect on properties has been one of the marks of the last 25 years. In the course of such studies, we have found that—true to the predictions of the theorists—metals can indeed be much stronger than they usually are if we can eliminate the minute dislocations that in the past have always been found within their crystalline structure. Perfect "whiskers" of many metals have been produced, with, for example, strengths as high as 2 million pounds per square inch in iron. At present, these remarkable specimens have been produced only in sizes comparable to that of a human hair. In the future, we may hope to develop methods of producing them in commercially usable sizes and shapes. If this proves to be the case, we may find many of our concepts in engineering radically revised. Structures will shrink to a mere shadow of their former selves, while retaining or improving upon their load-carrying capacities. While the most eye-catching results may lie in the field of architecture or transportation, the electrical engineer will certainly be a beneficiary too, as he designs the myriad products which require maximum strength with minimum weight.

The problem of where to find sufficient sources of electric power to run all the products created by the electrical engineers' imagination will continue to be a major concern. The problem of drawing useful power from the fusion reaction is, of course, one of the most challenging ones we face. As we noted earlier, many people are devoting a great deal of effort to it. I might merely point out that an interval on the order of 15 to 20 years lay between the proof of *technical* feasibility of fission power (1942, by Fermi) and the *economic* feasibility of fission power, which we have not demonstrated as yet. The confidence that the layman feels in the efficacy of scientific research is heartening, but there are times when confidence can be exaggerated, and if so it may turn into impatience. We must not go on the assumption that fusion power will be remaking our electric power technology the day after tomorrow.

THE FUEL CELL

A FUEL CELL is a device that directly converts chemical energy—the oxidation of a fuel—into electric energy. In simplest terms, a fuel cell is merely a primary battery which consumes cheap fuel materials instead of such relatively expensive raw materials as zinc, cadmium, or lead. The idea is attributed to the English scientist Grove, who first published on the subject in 1839.

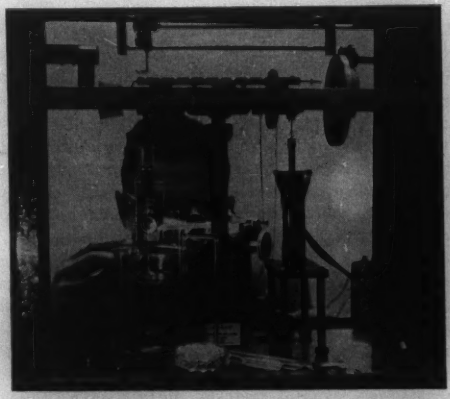
Theoretically, a fuel cell of 100% efficiency could be produced, and in the laboratory its efficiency with special fuels has actually approached that figure. After World War II, there was a resurgence of interest in fuel cells, and currently there are scientific efforts reported in West Germany, England, the Netherlands, and at several laboratories in the United States. Not long ago, the National Carbon Company announced the development of a fuel cell in which hydrogen and oxygen are combined to produce electric energy. This "electrolysis-in-reverse" system yields about one volt per cell and about one kilowatt per cubic foot. National Carbon reports efficiencies of 65 to 80%, and the U. S. Army is testing the new device for use in small radar sets. For bulk rather than specialty power generation, however, the fuel cell must burn cheaper conventional fuels, and at present it cannot do so with satisfactory efficiency and life.

That hydrogen is an expensive fuel seems paradoxical in view of the abundance of hydrogen and oxygen in a familiar combination that covers 71% of the earth's surface. But pure hydrogen—by itself—remains an expensive item. It appears, then, that the use of fuel cells will be limited in the near future to military applications, stand-by plants, and other systems where convenience or portability are more important than economy. Some of our scientists are optimistic about the long-term possibility of fuel cells, although they are very much aware of the difficult technical problems that remain unsolved.

SOLAR ENERGY

THE DIRECT CONVERSION of light energy to electric energy is most commonly observed in photographic exposure meters, but a more glamorous application is in what is popularly called "the harnessing of solar energy." Solar energy also can be achieved by thermal conversion, but most of the recent interest has centered around the photovoltaic process, which transforms light energy into electricity.

In our organization, we have made a thorough study of the economic and technological aspects of solar energy. Without going into detail, we will summarize



A "perfect whisker" of metal is strength-tested at GE Research Laboratory. Such whiskers, free from atomic imperfections, have extraordinarily high strengths.

by saying that before solar energy can become competitive, we must improve energy-storage techniques by about six times in comparison to best present practice, and must develop solar cells that are 100 times cheaper than anything now available. In summary, it seems safe to predict that solar energy may have a number of important specialty applications—including power for satellite transmitters—during the next few years, but in this country it will not be economically feasible for bulk electric power generation for many years to come.

There is no doubt that research and development operations have become, in just a few years, a major factor in our national life. We are investing our time and effort in these activities at a rate that has no parallel in history. We are all aware that this is so, but continued exposure to talk of billions of dollars may have numbed our sense of just how big is "big" in this connection. The January 1959 issue of *Fortune* may have put the matter simply enough with the estimate that during the next decade the United States will spend $120 billion for research and development work. This sum, the editors point out, will exceed the total amount spent on science and technology from 1776 to the present.

If the dollar figures are awe-inspiring, we can expect no relief when we turn to the "product" that is being produced by means of such massive expenditures. The output of science is information—to consider only the "R" in R & D, for a moment—and the information comes rolling out at a rate that should quicken the pulse of any statistician or archivist. One estimate has it that in a single year more than 13 million pages of scientific literature are added to the world's store. New scientific journals now number in the neighborhood of 15,000, perhaps more.

Certainly this outpouring of new knowledge is encouraging, at least to those of us who are committed to the idea that man can live a more rewarding life by learning more about his world. But it is equally clear that the task of "keeping up with Science" has become a job for an electronic computer, not a human. Even allowing for the usefulness of abstracts—or abstracts of abstracts—no man can hope to familiarize himself with all the significant work that is being done. Any attempt to predict the future in detail, therefore, becomes foolhardy: even the necessary information that might encourage an educated guess has become well-nigh unmanageable.

What, then, can we say of the future in research? Not long ago, wrestling with this same question, I came to the conclusion that we can at least say this:

Increasingly, scientific discoveries occur in areas of human need. Today's scientist is not completely at the mercy of a capricious nature. The tools of modern scientific research have become powerful indeed, and under the influence and pressure of a frontal research attack, an unwilling nature may frequently be made to yield a *desired* result. Generally speaking, you will find some validity in the statement that to an increasing extent in the future scientists will determine what discoveries need to be made and then plan to make them.

The plans will, of course, not always be successful. Mother Nature has the final word and may cast a veto. But the question of the final outcome of a research investigation is becoming more and more subordinate to the practical questions of probable cost, time required, and the availability of required scientific skills to accomplish the research. This will probably be true to a progressively greater extent in the future. Scientists will plan to make discoveries in areas of great opportunity and need, and the powerful tools and skills of modern research will implement the planning.

Radioisotopes

A New Dimension for Applied Science

W. E. BARBOUR, JR.
MEMBER AIEE

IT GOES WITHOUT SAYING that a look back over the past 25 years will show great changes in every branch of the applied sciences and especially in electrical engineering. Generators, transformers, switchgear, and transmission lines, for example, are designed today to operate at greater capacity, with increased reliability, more automatically, and at higher voltages than did their predecessors of 1934 vintage. Such changes, broadly speaking, are in the nature of improvements and constitute the development of electrical engineering as an art progressing as it has throughout the entire 75-year history of the AIEE. With this long history, it is no wonder that future electric machinery and equipment development can be forecast with some degree of accuracy.

Nuclear and radiation technology on the other hand, while fundamentally related to electrical engineering, has had its very origin as a basic science something less than 75 years ago with the almost simultaneous discovery of radioactivity by Becquerel in France and of X rays by Roentgen in Germany around 1896. The earliest physical concepts in the nuclear field that led to the use of radioisotopes and tracer techniques are thus not as old as electrical engineering as an applied science.

In fact, the scientific discovery of greatest significance to the engineer and the cornerstone for all future nuclear engineering was the identification of the neutron only about 25 years ago by James Chadwick in England. Chadwick observed the presence of the neutron while working on the origins of certain anomalies in some earlier experiments of W. Bothe and Frederic Joliot in 1931 and 1932. For, without knowledge of the neutron, nuclear and radiation phenomena would never have transcended from a basic natural science to a subject not only of great engineering and economic importance but as a basis for new weapons of unparalleled international political significance. Thus the nuclear field today, with less than one third of the historical base period of development of most other well-known branches of engineering, is somewhat less susceptible to accurate long-range forecasting. Its future may, therefore, provide some startling surprises and there is high probability of significant "break-throughs." This gives the nuclear field the same aura of excitement, pioneering, and adventure that the electric power and lighting industry enjoyed 50 to 75 years ago.

PRINCIPLES OF RADIOISOTOPE APPLICATION

TWO BROAD MAJOR APPLICATIONS of nuclear research have independently, in the 14 years since the close of World War II, provided a tremendous impact on electrical engineering and on the economy as a whole. Both became practical realities during the last 10 years because of the enormously accelerated wartime atomic program in the United States. During the war, results of nuclear research covering several previous decades were reduced to application in a few months under the pressure of the times.

One of these two broad areas of application is the generation of heat in nuclear reactors by the fissioning of uranium-235 or plutonium for conversion into electric energy, process steam, and power for the propulsion of ships and submarines. The role of reactors is described elsewhere in this anniversary issue. The second broad application and the one to be treated briefly in these paragraphs is concerned with the use of radioactive isotopes as tracers and as radiation sources in a variety of ways in therapeutic and diagnostic medicine, biology, physiology, agriculture, and industrial controls. These isotopes as abundant, low cost, compact sources of radiation have indeed provided a new dimension for applied science as aids to basic research and to improved systems for making extremely precise engineering measurements.

Radioactive isotopes were first produced in reasonable quantities as by-products from an atomic reactor at Oak Ridge, Tenn., which was originally designed to make plutonium for military use under the wartime "Manhattan Project." Because of the increasing importance of these "tagged" chemicals in their own right, radioisotopes are now more efficiently produced in several reactors here and abroad which have been specially adapted or designed for that purpose. The isotopes may later be incorporated by service laboratories into the particular synthesized chemical compounds most suitable for their ultimate application.

Over 1,000 radioactive or so-called labeled compounds are readily available, including bio-chemicals, pharma-

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Many helpful suggestions were derived from correspondence and discussions with key people in the radioisotope and nuclear instrument industry during preparation of this review and projection. Each of the following individuals outlined salient areas of development since World War II and projected important needs for future work. Their thoughts displayed surprising and reassuring congruity: John Kuranz, Nuclear-Chicago Corporation, Chicago, Ill.; Dr. Ernest Wakefield, Radiation Counter Laboratories, Inc., Skokie, Ill.; Peter Thomson, Baird-Atomics, Inc., Cambridge, Mass.; William Stenzel, Tracerlab, Inc., Waltham, Mass.; Dr. Paul Aebersold, and Oscar Bizzell, U. S. Atomic Energy Commission, Washington, D. C.; Michael Michaelis, Arthur D. Little, Inc., Cambridge, Mass.; John McMahon, National Industrial Conference Board, New York, N. Y.; F. H. Low, Picker X-ray Corporation, White Plains, N. Y.; E. M. Pollack, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.; and Dr. Ernest Anderson, Los Alamos Scientific Laboratory, Los Alamos, N. M.

ceuticals, and industrial chemicals. It has also been possible to label such organisms as blood cells, bacteria, viruses, and living plants.

In a few words, the fundamental principles involved in the application of radioisotopes may be reduced to three general modes of use. The first of these embraces a change in the specific physical condition of materials brought about by radiation. The second involves changes in radiation energy or flux density resulting from such radiation passing through or bouncing off certain materials. The third encompasses tracer applications in which quantitative and qualitative information on reactions can be studied using minute revealing radiation emanations rather than conventional physical or chemical measurements in order to improve the range, accuracy, or speed of reading. All of these three modes of use have become important in science and industry since 1946. More explicitly, they may be described as follows with pertinent illustrative examples:

Radiation Effects on Materials. In this first mode the radioisotope simply supplies radiation of a certain characteristic as to its type, energy, decay rate, and total quantity. This radiation impinges itself on a "target" which is thereby affected physically in some manner. A cancer patient may thus have metastases or a malignant growth arrested by controlled doses of gamma rays. A food product such as a potato or tomato may receive beta rays sufficient to eradicate micro-organisms which otherwise would cause decay or deterioration of the skin and, thus, prolong its unrefrigerated shelf life. Complex polymer molecules may be cross-linked one to another by gamma radiation with resulting desirable increase of both electrical resistance and melting point. A phosphor may be excited to luminescence by radiation from a radioisotope in its vicinity or one chemically incorporated into the phosphor itself providing a new group of self-luminous materials.

Materials Effect on Radiation. In this second mode, a material intercepting the path of beta or gamma radiation selectively absorbs a definite amount of such radiation furnishing in the process valuable information about the material itself such as its density or thickness or the presence and location of flaws or voids. Such applications include both industrial and clinical radiography as well as the continuous measurement and control of thickness and density of moving sheet material such as rubber, plastic or paper in the process of manufacture.

Tracer Applications. In this third mode, a radiation producing "tracer" chemical containing a suitable radioisotope may be substituted for its stable and normal counterpart without altering in any way either the chemical or physical properties or processes involved. Then, throughout the usable life of the radioisotope, radiation from these substitute tracer atoms can be detected with sensitive instruments thereby disclosing the presence, rate of travel, or concentration of some material in an otherwise inaccessible closed system such as the human body or a chemical process plant. Tracer applications have actually become the most important current use of radioisotopes.

Dilution determination as a form of tracer use is especially suited for determining the amount of a substance present in such low concentrations that it could not be detected by chemical or other more conventional methods. For example, it is possible to detect a radioisotopic tracer which has been diluted to 1 part in 10^{17}. Spectrographic and chemical methods used prior to such radioisotope technique would permit detection after dilution of only 10^{5}. Dilution measurement is predicated on obtaining homogeneous mixing of the labeled or radioactive with the unlabeled or normal substance. The amount of a given material originally in the system, which might be water in a reservoir supplying a hydroelectric plant, may be computed from the ratio of radiation from a withdrawn sample at the penstock to the known amount of radiotracer added in the reservoir in the first place.

Activation analyses provide still another aspect of tracer use. Here a neutron source, such as may be obtained with a polonium–beryllium mixture, by a high-voltage discharge in deuterium–tritium tube, or even by a small nuclear reactor, can produce new radioisotopes. These are usually of very short half-lives and are therefore especially useful because they are made on the spot for instant use or measurement but decay to relatively low levels in a few days time, thereby eliminating considerable hazard. This hazard reduction has a unique advantage for use in connection with consumer products. As a possible example of activation analyses consider that a neutron source is lowered down an oil well so as to traverse its vertical profile causing certain elements characteristic of a strata or subsoil to be converted into short-lived radioisotopes of those elements. A detector coincidentally or later following the same vertical traverse could then be used to identify the nature of and precisely locate certain of these strata providing valuable data on the geological formation for locating oil and for later working the well.

The gamma spectra resulting from neutron scatter is now used routinely to identify carbon, calcium, and oxygen in substrata using such neutron and detector down hole techniques.

It now seems appropriate to illustrate several of the typical engineering applications of these three modes of radioisotopes in order to conjecture on their future possibilities, correlating such examples with the developments in instrumentation and nuclear measuring systems that made them possible. With the exception of a limited few chemical and optical techniques, all important nuclear instruments are basically electrical and count heavily on electrical engineering discoveries of past decades for their performance.

Like many other electric systems, nuclear measurements, and controls whether for research, medicine, or industry, are performed by a series of interconnected subsystems. A block diagram of a nuclear or radiation

control system might consist of a sensing element such as a Geiger tube or scintillation crystal followed by an electronic amplifier, a computing device, an electrical feedback for control function, plus power supplies and some suitable means of reading out or recording events.

SENSING DEVICES

NUCLEAR INSTRUMENTS and control systems employ much the same type of circuitry and gear for the most part as are used in other electronic controls. The major exception is in the sensing devices for first detecting and then amplifying nuclear "events" up to a level where conventional electronics can take over. These sensing devices are, in general, unique to the nuclear field.

The property of gases to become electric conductors under the influence of ionizing radiation has provided the detection procedure most widely used to date in the quantitative study and use of alpha and beta particles and indirectly of gamma or X rays. Such quantitative measurements are based on either the counting of individual particles and gamma-ray photons or on determining the total radiation received in a given time interval.

Ionization Chamber. An ionization chamber such as the pistol grip "Cutie-Pie" shown on the table in Fig. 1 and held by the monitor in Fig. 2 is calibrated to read in milliroentgens per hour. A roentgen is a measure of quantity of gamma radiation capable of producing, as a consequence of ionization one electrostatic unit of electricity in 1 cubic centimeter (cc) of dry air under standard conditions. Such elementary chambers were first used by Madame Curie and by Rutherford around 1900 and are today the principal means of detecting beta rays for such important uses as in the highly automatic beta gauge for controlling the thickness of sheet material in the process of manufacture. One of the chief limitations and, therefore, an area for further development in ionization chamber use is occasioned by the extremely small currents involved (micromicroampere level) and the resulting dependency on stable conditions of temperature, pressure, and humidity of the gas (frequently air) between the electrodes. Also the d-c amplifier following the chamber must be kept free of drift at these low current levels. Wide ranges for reading can be obtained through the use of circuits which provide logarithmic scale calibration.

Courtesy of Nuclear-Chicago Corporation

Fig. 1. Examples of the wide variety of radioactivity measuring systems now available from commercial suppliers.

Courtesy of Nuclear-Chicago Corporation

Fig. 2. Measuring machine tool wear with radioisotopes saves thousands of hours, produces accuracies impossible with other analytical techniques. Scaler and well scintillation detector are used.

An ionization chamber may be connected to a suitable linear amplifier for distinguishing between alpha particles and all other ionizing radiation. Such a device is often called a kicksorter and it responds only to pulses exceeding a certain minimum and then sorts and counts them according to size. Radiation, in this way, can be identified and counted even if occurring from several radioelements in a mixture.

Electroscope. A special electrostatic type of ionization chamber is the Lauritsen or quartz-fiber electroscope. This instrument consists of a fine metal-coated quartz fiber connected to a parallel rigid wire and mounted in an insulated aluminum cylinder. An applied momentary charge results in the rigid wire repelling the flexible fiber. Then, when this electroscope is subjected to ionizing radiation, the wire and fiber collect ions reducing the charge and, in so doing, decrease the repelling force between the wire and fiber. These physical changes are observed usually through a microscope with a scale or reticle. The electroscope acts as an integrating device showing the total amount of radiation received in a given period of time. Other forms of electroscopes involve the measurement of weak current changes on ionization leaving the charging battery attached.

Proportional Counter. An extension in the use of ionization chambers alleviating the necessity to employ such sensitive electronic amplifiers is the proportional counter. Ionization of the gas in the chamber, if the voltage gradient is somewhat higher than in the case of the ionization chamber, causes a multiplication of an avalanche effect. A single primary ion pair results in 100,000 to 1 million new ion pairs constituting a pulse, which can in turn be measured. The amplitude of the resulting pulse will, in general, be proportional to the energy of the primary ion pair triggering the avalanche. Heavy alpha particles with mass of some 1,837 times that of beta particles will give much larger pulses in such a counter than either betas or gammas. Hence,

Courtesy of Picker X-ray Corporation

Fig. 3. Detecting head containing scintillation phosphor crystal and photomultiplier amplifier.

such a counter is useful in selectively counting alphas in the presence of betas and gammas.

Geiger–Mueller Tube. On still further increasing the voltage between electrodes to perhaps 1,000 volts or more of this 2-element simple device or "chamber," a region is reached where the size of the resulting pulse is quite independent of the energy of the incident event or ray entering the area between the electrodes. The resulting sensing device known as a Geiger–Mueller tube or counter is very widely used for counting the total number of ionizing events. However, the significance of such quantities can be related to fundamental units such as the Curie (quantity of radioactive nuclide producing 3.7×10^{10} primary disintegrations per second) only after taking into account a number of approximations relating to tube efficiency, absorption by its window and geometric configuration of the setup for measurement. The Geiger tube is most frequently used in making ratio readings or relative total counts among samples under identical geometric and other conditions. It is interesting from another point of view in that it attains a gas amplification factor in the order of 100 million, thereby reducing the inherent sensitivity required in the electronic amplifiers to follow it as compared with the straight ionization chamber previously described.

Geiger tubes are made in a wide variety of shapes and sizes from 1 cm to 1 meter in length and they operate on a so-called plateau or d-c anode voltage of 300 to 3,000 volts. Their output pulses are usually counted as random events on digital devices or scalers at rates up to 15,000 per second or higher.

Windowless Counter. The Geiger tube as referred to consists physically of a conducting shell or cathode and center wire with a positive high voltage applied and a thin membrane such as mica of about one to ten thousandths inch thickness on the side or end to serve as a window to admit as much as possible of low-energy radiation. Certain radiations, such as the beta particles from carbon-14 and from sulfur-35, are extremely weak and hardly energetic enough to penetrate the thinnest of such windows in sufficient quantities to afford relatively efficient counting. Therefore, since about 1950 so-called flow counters or windowless Geiger tubes have made measurements of the very important carbon-14, sulfur-35, and hydrogen-3 isotopes more feasible.

Scintillation Counter. Another type of sensing device known as the scintillation counter also dates back in principle to the time of Becquerel, who in 1899 observed that radiation produces luminescence in such substances as zinc sulfide. Until 1930, such phenomenon as in the case of Crooke's spinthariscope (an optical device for observing individual nuclear events as magnified flashes on a phosphor, circa 1903) served as virtually the only quantitative and qualitative method of studying alpha particles. However, since 1950 the development of the photomultiplier tube as a means of obtaining a measurable current from such minute light sources as these crystalline phosphors has opened up a faster, more efficient, and more rugged sensing method for many more applications than the Geiger tube could ever provide. Scintillation counters while originally developed for alpha counting are today more generally used for betas and gammas as well. (See Fig. 3.)

Cloud Chamber. Of both historical and current experimental scientific interest is the Wilson cloud chamber. This instrument goes back to 1911 in its origin. It operates on the principle of saturating air with water vapor under the influence of an ionizing radiation and then cooling the chamber by sudden expansion of its volume. A single ionizing particle can be observed by the reflection of light on a water droplet over a dark background. Collisions and free paths of particles can be observed and photographed with the cloud chamber. In addition to its educational value, it is important in cosmic ray research and in basic studies of nuclear collisions and disintegrations.

Film. The first use of special photographic plates in recording ionizing particles also dates back to the discovery of radioactivity by Becquerel in 1896. In recent times, and with improved emulsions, film has come into wide scientific use in connection with the detection of tracks of charged particles and of neutrons by adding boron to the emulsion. But relatively more important are two practical applications of film techniques. The first is in large-scale routine radiographic work using an isotope or X-ray source to detect flaws in pressure vessels, pipelines, and castings. Gamma rays from cobalt-60 or cesium-137 are energetic enough to penetrate several inches of steel and other dense material and show up flaws or variations by the degree of blackening of photographic film which has been placed on the opposite side of the object being tested from the radiation source.

A not inconsiderable secondary use of film as a detector is in the film badge used generally for recording

cumulative exposure to radiation of personnel. In the film badge, which is usually worn on the clothing of an individual for a specific period of time, the degree of film darkening under various wedges or filters can, by densitometer comparisons with standards and control films, indicate roughly the total roentgen dosage collected and differentiate between gamma and beta radiation. The introduction of certain filters also makes it possible to record neutron tracks photographically. These can be observed through microscopic analysis of the film to determine the approximate neutron exposure as well. A project to replace the tedious visual track counting by electron beam scanning has been under way for several years in the Airborne Instruments Laboratory, a division of Cutler-Hammer, Inc. When this is perfected, it will greatly facilitate neutron exposure measurements with film.

Chemical Dosimetry. It is perhaps necessary to mention here the use of a chemical incorporating a color changing pH indicator and some substance which alters the pH under ionization as a relatively insensitive high-radiation-level dosimeter. Chemical dosimeters may consist of pocket-sized banks of transparent tubes of progressive sensitivities mounted near stable color comparators or standards. At present, chemical dosimetry is mostly of interest to the military in connection with determining the time when an area is safe for personnel to enter after atomic bomb contamination.

Summary of Sensing Devices. Currently, of all methods of sensing radiation phenomena from nuclear or X-ray sources, the scintillation approach has the greatest near-term promise. However, photomultiplier devices like Geiger tubes are inherently delicate and expensive. Requirements to measure radiation levels in space from satellites and rockets are putting high environmental demands on such devices even before sufficiently ruggedized industrial models have been perfected. It would seem that the most hopeful long-range approach for better radiation detectors and sensing devices lies in the realm of solid-state units perhaps related to certain semiconductors. The ultimate aim for most important future applications is small size, rugged nonbreakable construction, low output impedance (as compared with Geiger tubes), stability through wide variations in temperature and humidity, and last but not least low cost. Transducers and sensing devices for measurement of pressure, temperature, and mechanical deflection are today more satisfactory in regard to size, durability, and cost than almost any corresponding nuclear detector. A reasonably priced low-impedance solid-state device capable of detecting weak beta and gamma radiation as well as one for fast and slow neutrons would greatly extend the use of radioisotopes in industry, medicine, and agriculture and, of course, would be of great value to the military for space vehicles.

It is interesting to note that virtually all basic types of sensing elements now in use—the Geiger tube, scintillation counter, electroscopes, film, and ionization chambers—were invented and used at the time of or very shortly after the discovery of radioactivity some 50 years ago. Even the measuring devices for neutrons, unknown until 1932, employ secondary effects from the aforementioned basic principles of detection. This should suggest that other radically new concepts of detection may be possible such as with solid-state devices.

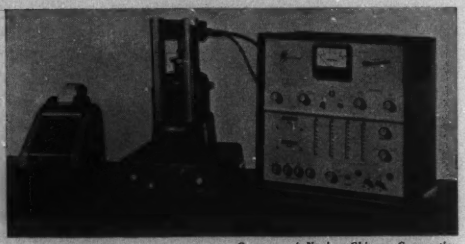
INSTRUMENTS

As WITH ALL ASPECTS of engineering, progress in the nuclear realm is directly related to the development of instruments and measuring techniques. Until about 1947, the measurement of radiation consisted of a laboratory approach in which the sensing elements just described and built in the laboratory were almost sufficient in themselves for reading nuclear quantities. However, after World War II the more abundant reactor produced radioisotopes inspired a new look at instrumentation. A number of small commercial companies were organized both in the United States and abroad, and rather elaborate self-contained scalers, rate meters, power supplies, portable survey instruments, and a host of electrical and mechanical accessories were developed for general use. At first, these instruments left much to be desired in dependability, especially for day-in and day-out use in hospitals and in process industries. Many laboratories purchased standby equipment in order to insure that their research work would be uninterrupted by instrument breakdown. After 1950, quality improved and users became confident that the commercially available instruments would give dependable and reproducible readings. These reliability problems did not originate entirely with the instrument manufacturers since certain components such as satisfactory high-voltage regulator tubes and low-leakage connectors were not available before about 1951. (See Fig. 4.)

Courtesy of Tracerlab, Inc.

Fig. 4. Basic solid sample counting equipment consists of simple scaler with preset count, manually operated sample changer, and scintillation probe. Use of scintillation probe instead of Geiger tube allows greater flexibility and higher efficiency for gamma counting.

Scaler-Printing, Timer-Sample Changer. As radioisotope users expanded their interest in this new scientific tool there arose a need to handle the more tedious measurements automatically. Many jobs required the routine counting of literally thousands of samples. Today, practically every well-equipped isotope laboratory



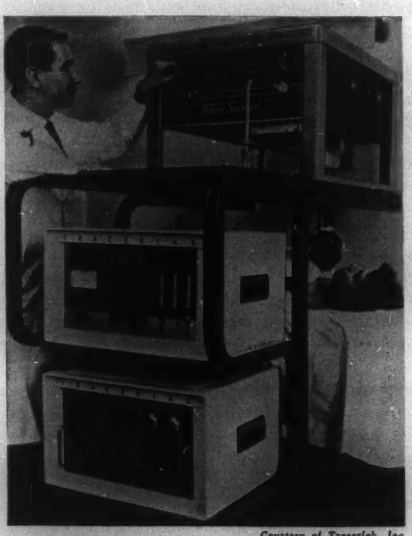
Courtesy of Nuclear-Chicago Corporation

Fig. 5. Development of automatic sample changer eliminated tedious and time-consuming manual counting of samples. This system counts up to 35 samples and presents printed radioactivity data of each sample.

has at least one of the various scaler-sample, changer-printing timer combinations such as is shown in Fig. 5. In this arrangement, some 25 to 100 prepared samples can be loaded at one time and with the interconnection to a printing read-out mechanism, scaler and sensing element, a simple push of a start button can set in motion work that would otherwise require many hours or days of a technician's time. The system, on the one hand, can be set up to count up to 100,000 predetermined nuclear events per sample or, on the other hand, it may count each sample for a specific time interval, recording on tape the required readings and ambient radiation background information. These installations are now in everyday use in industrial laboratories, hospitals and research centers. The data these scaler assemblies furnish is usually in the form of "counts per unit of time" and not related to fundamental units such as the curie. In counts per minute, percentage or ratio comparisons can be readily made for tracer studies, dilution determinations, and other techniques mentioned earlier.

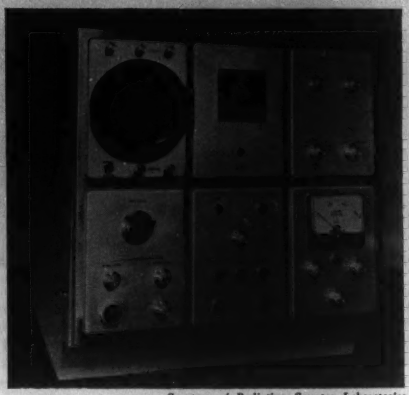
Counting Rate Meters. While the scaler is essentially a digital device for counting nuclear events in pairs or tens, there is an equally important need for an analog instrument. Various forms of counting rate meters which electronically integrate the progression of random counts picked up by the Geiger tube or scintillation crystal are in general use. Such instruments may be used directly to actuate a switch at average counting rates above or below a predetermined value. For example a suitably placed Geiger tube and counting rate meter using backscattered radiation from an external nuclear source can sense or find the level of a liquid in a closed tank and actuate valves automatically to maintain constant level. Similarly, in cross-country pipelines, the interface between different petroleum products may be marked by the injection at the point of origin of a relatively short-lived radioisotope. When the interface approaches the terminal perhaps hundreds of miles distant, it can be detected by a Geiger tube connected to a counting rate meter and cause valves to operate so as to minimize loss through intermixture of the two petroleum products. In cases where the densities of the two liquids differ sufficiently, their respective rates of absorption or scatter of gamma radiation can be used to accomplish the same result without even the necessity of injecting radioisotopes to mark the interface.

Gamma Spectrometer. In addition to becoming much more reliable, nuclear instruments have greatly expanded since 1950 in terms of the information they provide. One of the most important instrument concepts to be developed in the past 10 years is the gamma-ray spectrometer, which is capable of reading specific energies of individual pulses or rays. In a sense, this technique of nuclear spectroscopy is as great in importance in nuclear observation as was the microscope for optical measurements many years ago. Through the use of multichannel analyzers, with each channel properly gated to admit pulses of only a certain energy level, and taking readings on printed tape over a period of time, the system automatically identifies the presence



Courtesy of Tracerlab, Inc.

Fig. 6. Mobile isotope detection and measuring equipment speeding diagnosis in the medical field has led to development of automatic recording equipment for finding and measuring concentration of isotopes in patient. Automatic scanning device measures size of thyroid and relative concentration of orally administered isotopes in it. Using pulse height amplification instrumentation, it discriminates between various energies of radiation spectrum, can detect one isotope in the presence of several others.



Courtesy of Radiation Counter Laboratories

Fig. 7. A 128-Channel Analyzer capable of scanning variously shaped random pulses as produced by individual rays or electrons in the detector and sorting them according to amplitude.

and relative quantity of each of a large number of radioisotopes in a mixture such as fission products from a reactor. This, in effect, is "three dimensional" spectrometry and its extension of the horizons for measurement is obvious. The multichannel analyzer using a scintillation detector is capable of performing spectroscopy and pulse-height analyses for scanning random pulses of shorter duration than one microsecond and of various amplitudes and shapes—sorting them according to amplitude into 100 or more separate channels (Fig. 7). Then the record of the counted pulses may be stored in a magnetic core memory for observation on a cathode ray screen or printed in decimal form on a tape after it has accumulated all of the data being sought. In addition to its wide use in spectroscopy, it has many applications in medical research, neutron time-of-flight studies, radioactive fall-out determinations, oil-well logging, and reactor-shielding studies. Multichannel analyzers are commercially available in from 2 to 100 and even 128 and 256 separate channels.

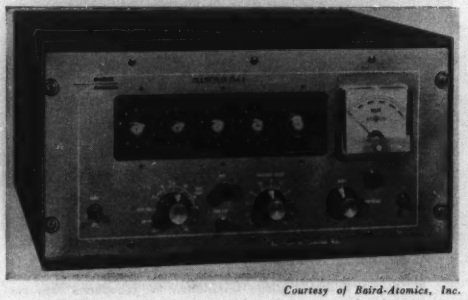
SPECIAL COMPONENTS

Decade Counting Tubes. A number of component devices of special interest have been developed for enhancing and facilitating nuclear measuring techniques. Some have found uses in other than nuclear measurements. It would be impossible to describe all. An example of a component developed for nuclear scaling and now in use in computers of all sorts is the multicathode glow tube. This tube is primarily a scaling device factoring in tens with the added feature of providing a simple direct display system. It was evolved from the original work in Sweden by Alfven directly after the war on a precursor tube known as the Trocotron. Various types of decade counting tubes, both vacuum and gas filled, are made in the United States and abroad for counting both regularly spaced and random pulses and in computation. Because of its counting speed limitation to some 20,000 counts per second, it is generally necessary to use one or more fast scales ahead of the first decade glow tube. (The Philips decade tube is faster but is not used widely in the United States because of its cost and circuit complexity.)

The tube and one of its nuclear applications are shown in Fig. 8. Incoming electrical impluses cause a glowing spot to move progressively from cathode to cathode around the tube's periphery. One move takes place per impulse received indicating the digits of 0 through 9 on the surrounding face or bezel. Because output can be taken from as many as 12 cathodes, the tube can be used for electronic switching, frequency division, or timing.

Radioactive Batteries. An excellent example of a unique component made possible by recent advances in basic science is the nuclear battery. Although these very low-current devices (in the order of 10^{-9} amperes at approximately 2 volts) are still limited to long shelf life or standby use as reference voltage sources such as in missiles and rockets, they hold much promise for more general consumer applications. One type of battery functions by converting alpha- or beta-ray energy directly into electric energy by ionizing a gas using a long-lived radioisotope such as strontium-90, with a half-life of 20 years, hydrogen-3 (tritium) with a half-life of 12 years, or thorium-229 with a half-life of 7,300 years and collecting the ionization current by the field produced between the two dissimilar metals in contact.

Early in 1959, The Martin Company working on a defense contract announced an experimental battery using 3,000 curies of polonium-210, a naturally occuring radioactive element with a half-life of 138 days. This battery while prohibitively expensive using such a large quantity of polonium did prove that practical though still small amounts of energy could be derived by such direct conversion of nuclear energy. The battery operating with an efficiency of 5 to 6 per cent was capable of producing about 5 watts continuously for 6 months or more. With cheaper fission-product isotopes



Courtesy of Baird-Atomics, Inc.

Fig. 8. Scaler using five "Dekatron" counting tubes with light shield and bezel cascaded so as to furnish maximum scale-down factor of 100,000.

it has a real potential. A 100-watt model using strontium-90 is now being constructed.

The energy for converting ionization in a gas to electrical energy is derived from the ionization of the gas itself and, therefore, actually originates from the radiation energy of the isotope used. The nuclear battery will certainly find broad application in electronics and measuring instruments where a stable long-lived, low-power reference voltage is required and where short-circuit conditions in the system might render conventional dry cells useless.

NUCLEAR SYSTEMS AND TECHNIQUES

QUALITY CONTROL is one of the last manufacturing functions to yield to automation. Human judgment of the final product through inspection and sampling has long been regarded as a necessary final operation to insure quality and consistency. In the continuous manufacture of sheet material such as plastic, paper, roofing, metal foils, coated or plated metal sheet, foam rubber, tire stock as well as tubing, textile fibers, and cigarettes any contact with the fragile, thin, fast-moving material for gauging is usually impractical.

Beta Gauges. Early in 1947 product development work was originated at Tracerlab, Inc., Boston, Mass., based mainly on several references in technical journals and certain stated requirements of the Celanese Corporation for a noncontacting gauge to measure and control through automatic feedback the thickness of sheet material or coating. The total thickness is determined by a so-called transmission gauge in which a product passes between a suitable radiation source such as beta emitting radioactive strontium-90 or krypton-85 and an ionization chamber detector. Absorption of radiation from the source by the material is a function of the mass density of the material. The gauge effectively measures the weight per unit of area of the sheet material. For most gauge applications the material must be homogeneous.

Courtesy of Tracerlab, Inc.

Fig. 10. Pair of beta gauges control thickness of sheet material by actuating screw-down motors (*upper left*) on each side of calender. Overcorrection or hunting is eliminated through use of graduated control steps. Gauges consisting of C-frame holding radioactive source and ionization chamber are at far left. Gauge control units and potentiometer-recorders are in front of operator at right.

Associated servomechanisms and feed-back devices connected to the sensing head then can continuously control the production process in order to maintain constant thickness strictly to much closer tolerances than is possible manually without stopping the machine to take samples. Resulting savings in material as well as improved quality control have been estimated by the U.S. Atomic Energy Commission (AEC) to save more than $100 million annually. Products that are rapidly moving, high in temperature, soft, very thin, or are easily marred are usually better measured by radioisotope gauges than by other means of control. (See Fig. 9).

Courtesy of Tracerlab, Inc.

Fig. 9. Modern thickness gauge installation for cellophane tape controls thickness of adhesive coating on tape prior to slitting. Uniform thickness is maintained by reading thickness of sheet before and after application of adhesive. Note explosionproof electrical connections.

Backscatter Gauges. Another equally important gauge for measuring the thickness of a coating laid over a base material as with tinplate, lacquer, glue, asphalt, and carbon paper coatings is the reflection or backscatter gauge. In principle, a radiation beam is directed through the coating to the base material. Changes in reflected radiation are proportional to the thickness of the coating and can be measured and used to control to tolerances of a few ten-thousandths of an inch in many cases. Paper, rubber, or plastic sheet may thus be measured and controlled as it first contacts the calendering rolls, which with applicable electronically produced time delays and feedback devices can correct any deviation from the desired tolerances as it occurs. Raw material is saved and scrap often drastically reduced.

Gamma Gauging. For thicker material such as steel produced in a rolling mill, gamma, or X-ray sources are being used to some advantage. Since gamma attenuation by the material being measured does not exhibit the sharp linear cutoff as in the case of an ideally beta source for a thin material, gamma gauging is inherently more difficult and less precise. Also the requirement for

noncontacting gauges for hard surfaced thick materials is usually less acute. Therefore, gamma gauge development is lagging about 10 years behind beta gauge utilization. (See Fig. 10.)

Bremstrahlung Units. A form of beta gauge has recently come into use consisting of a nuclear control device to generate beta-excited X rays, which are in general less energetic than gamma rays. These are called Bremstrahlung gauges in recognition of the backscatter X-ray phenomenon employed. They thus provide greater sensitivity and less severe shielding requirements. Such gauges are used in addition to thickness control for liquid-level packaging operations such as with liquid detergents, antifreeze, powders, beer, and other automatically packaged products. An aluminum target near a 100 millicurie strontium-90 beta source produces X rays of about 100 kilo-electron volts (kev) peak similar to an X-ray machine of this rating. With a pair of opposing heads one containing a strontium-90 and light source and the other a Geiger tube and photocell aligned respectively, the system can be connected to actuate a mechanism for rejecting any improperly filled containers.

Penatron. Many special-purpose radiographic types of gamma gauges are already in general use. One of these known commercially as the Penatron developed by Dr. Herzog, Texas Development Corporation, Bellaire, Texas, is used in both transmission and reflection form to measure eccentricity, corrosion, or flaws in pipes and tank walls.

Soil Density and Moisture Gauge. Rugged battery-operated portable instruments have been developed to measure soil density and compactness using the gamma backscatter principle already described. Closely related to the soil density gauge is a gauge which reads the amount of moisture. With either instrument, the soil moisture or density readings can be taken in 5 or 6 minutes to ± 5 per cent accuracy, a significant improvement over other non-nuclear methods. (See Fig. 11.)

The principle of operation of such a neutron moisture gauge is of special interest. A 1-inch diameter access tube is placed approximately 10 feet into the soil. A neutron source and detector probe is lowered through the access tube. Fast neutrons emanating from the source are slowed by elastic scattering collisions. Inasmuch as hydrogen atoms have a very high cross-section or stopping power for elastic scattering, the neutrons lose a large fraction of their kinetic energy. The energy difference is readily measured using a boron trifluoride neutron-sensitive Geiger tube or scintillation crystal. Furthermore, it is directly related to water content since moderation of neutrons by the hydrogen in the water is very high in relation to moderation by other elements in the soil.

Radiocarbon Age Dating. It is, of course, impossible in any such summary as this to do more than touch on a few typical examples of radioisotope techniques. In some contrast to the industrially important beta gauges for controlling cigarette firmness or sheet thickness or the soil moisture, control is an ingenious nuclear system of geological age-dating of carbon-containing materials. This system utilizes the decay rate of long-lived radioactive carbon-14 as a yardstick. It represents an entirely new approach for deriving specific information not heretofore obtainable by scientific methods. Further, it employs techniques for counting radioactivity at very low levels representing an important area of future interest for greatly extending the usefulness of radioisotopes for other purposes.

It is well known that energetic cosmic radiation form neutrons in the upper rarefied atmosphere some 40,000 to 70,000 feet above sea level. These neutrons, with initial energies in the order of 5 to 10 megelectron-volts (mev), collide with air molecules thereby decreasing their energy to the point of thermal velocities. Such thermal neutrons may then react in several ways, one

Courtesy of Nuclear-Chicago Corporation

Fig. 11. Reliable and trouble-free Geiger tubes and proportional detectors have made possible designing of field instruments for soil moisture and density determinations. Technician uses the "d/M-Gauge" for determining density of compacted roadbed.

of which is to form through collision with atmospheric nitrogen the 5,500 year half-life weak beta emitting carbon-14 (C-14).

This radiocarbon formation from cosmic rays has long ago assumed a state of equilibrium insofar as the atmosphere is concerned with the normal decay of the same radiocarbon. Dr. W. F. Libby at the University of Chicago has predicted a continuous or equilibrium inventory of C-14 of 81 metric tons or 365 million curies over the entire earth.

It is assumed that a few hours after formation, the C-14 atom will oxidize to a $C^{14}O_2$ molecule and will intermix with normal stable atmospheric CO_2. Since plants, and ultimately thus animals, consume this CO_2, both will be radioactive. Assuming then that cosmic radiation has remained at its present level or intensity for at least 25,000 years and the world "carbon reservoir" has not changed appreciably in this time, then

there should be a present complete balance between the rate of disintegration of radiocarbon atoms and the rate of assimilation of new radiocarbon atoms for all carbon containing material in the life cycle. A living plant or other organism is, therefore, in a state of equilibrium between the cosmic radiation and natural decay of the radiocarbon. On death, however, this assimilation of radiocarbon is abruptly halted and only disintegration of the radiocarbon continues, reducing exponentially with time because of the decay of the radioactivity of the specimen. Potassium constitutes another source of plant and animal natural radioactivity, since one part in 10,000 of naturally occurring potassium is K-40, a weak beta emitting isotope.

Through careful measurement of radiocarbon content of specimens of ancient relics, coal, oil, and shell type material can provide to an accuracy of 2 to 15 per cent the age in years of the material or more specifically the elapsed time since its death or removal from the life cycle. These measurements have practical significance in geological determinations in studying oil and coal formations as well as the obvious archaeological implications. Special beta counting techniques often requiring readings below normal background or radiation noise levels were developed for this application.

Nuclear Machines. The role of nuclear machines in the development of atomic science would make a subject as broad and as important as radioisotopes. There is space only to mention a few by name. These include the cyclotron as first invented by the late E. O. Lawrence at the California Institute of Technology in 1931; the Van de Graaff; the Cockroft-Walton; the synchrotron; the 6 billion electron volt (bev) bevatron at Berkeley, California; the 2.5 bev cosmotron at Brookhaven, N.Y.; and many other ramifications of atomic particle accelerators. They are important electrical engineering concepts of extreme value to the physicist in uncovering further knowledge of the atom and the mysterious binding forces that hold its nucleus together as a stable concentrated mass. The bevatron at Berkeley, for example, is notable for confirmation of antimatter (antiprotons and antineutrons) which on collision with ordinary protons or neutrons respectively results in annihilation or complete conversion to energy. Two million-volt production-designed Van de Graaff electrostatic generators developed by the High Voltage Engineering Corporation, Burlington, Mass., have been sold commercially since about 1947 for therapeutic medical application, especially in the treatment of tumors and in basic research. While the Van de Graaff and resonant transformers are the work horses in the realm of high-voltage apparatus, an international race is taking place in the construction in the Soviet Union and the United States as well as in Switzerland, England, and France of huge machines capable of accelerating protons (positively charged hydrogen nuclei) up to 25 billion electron volts. The largest United States machine, known as an alternating gradient synchrotron, is located at Brookhaven National Laboratory on Long Island. It is fed moderately accelerated particles from a 750 kev (kilo-electron volts) Cockroft–Walton apparatus followed by 12 radiofrequency accelerating stages. When these large machines now under construction are operational around 1960-61 much new information on the nature of the "elementary" particles of the subnuclear universe is expected.

THE FUTURE

IN THE NEXT 10 YEARS, the usefulness of radioisotopes may be increased many fold through the extension of knowledge in two opposite directions at the same time —to the realm of high-level sources and into still lower level counting techniques.

High-Level Sources. On one hand reactors will produce in the near future previously undreamed of quantities of fission products such as cesium-137. A recently constructed plant at Oak Ridge is capable of separating 200,000 curies of cesium-137 per year for sale and general use. Cobalt-60 sources (made by high-energy neutron bombardment of Co-59 in a reactor) can now be made of radiation strength equivalent to all of the mined radium on earth before 1946. (*Time*, Jan. 12, 1959, stated that the Richland, Wash., GE Plutonium Works each year produces isotopes with 140 times the curie strength of the present world supply of radium.) Iodine-131 and other fission-product isotopes have been reduced in price to less than one-thousandth of the cost of those produced in early cyclotron operations. The sheer abundance of these large radiation sources as by-products of reactor heat and power generation will promote intense interest in finding new uses particularly since safe disposal of these is expensive. One of the direct benefits of large sources of radiation may be in the field of agriculture and food preservation by such radiation. In the United States, it has been estimated that some 10 per cent of the grain crop is lost through insect infestation. In hot humid areas, the loss caused by insects frequently rises to 40 per cent or more of the harvested cereal. While farm surpluses are a problem in the United States, world population has been growing at a greater rate than the world agricultural output. Although it is recognized that food preservation by radiation is still in an early stage, it is expected that many foods may be found that will be amenable to the radiation process with a resulting increase in available world food supply.

Specifically promising uses of radioisotopes in the years immediately ahead include the processing of pork products to eliminate trichina, seed mutations to improve strains, the irradiation of soils to reduce nematodes through sterilization with neutron bombardment with a portable reactor, the control of pests such as the screw-worm and the preservation of many types of concentrated foods without refrigeration which is of interest to the military. (S. G. Wildman and A. Norman of the University of California at Los Angeles estimated cost of nematodes to United States farmers at $10 billion annually and proposed reactor on wheels to sterilize top soil with neutron bombardment).

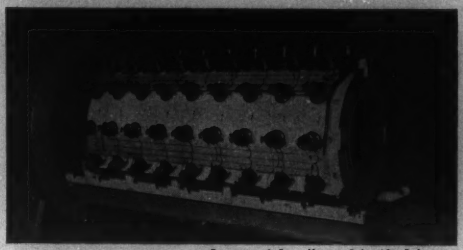
For some years, large sources have been promoted for accelerating certain chemical reactions as polymerization and chlorination. In addition to future sterilization of foods and drugs during packaging and chemical reaction uses, large sources will continue to be employed more and more for radiographic inspection during the manufacture of machinery and the construction of plants.

Low-Level Counting. At the other end of the scale, the continual lowering of measurable levels of radiation through the use of liquid scintillation counters and special techniques involving thallium-activated sodium iodide crystals, as shown in Fig. 12, may hold even more promise than the megacurie applications. Libby's age-dating work has greatly accelerated development of low-level counting techniques. Further applications of low-level work await only the advent of more rugged, portable, and lower cost instruments sufficiently sensitive to permit routine readings of radioactivity at or below normal background levels. Such instruments would, for example, permit continuous tracer controls of consumer products during manufacture.

While the human spectrometer shown in Fig. 12 can read gamma radiation from cesium-137 or radium-226 to a thousandth of a microcurie at levels of a factor of 10 to 100 below natural potassium-40 content of the body, the cost at $50,000 to $100,000 is too high and the equipment not yet adaptable to regular industrial and chemical usage. A walk-in variety of such a shielded low-level counter erected at the Geneva 1958 atomic exhibit had some 5,000 visitors. The potassium-40 specific activity in a normal adult is about 0.013 microcuries or about the same as the carbon-14 specific activity found in a 30,000 year old sample as used in Libby's age determination method. Recent instruments are capable of measuring this level of activity to a precision of ± 3 per cent in about 2 minutes. For industrial low-level tracer control work, this speed and accuracy might be improved.

Rare Earth Applications. Among the fission products are to be found some six of the rare earth elements in radioactive form. On account of the similarity of their chemical properties, separation by conventional chemical or fractional crystallization methods have not been practical and work is under way using ion exchange techniques with some degree of success. Expanded uses for rare earths, both stable and radioactive form, undoubtedly will be found (as was the case with aluminum, zirconium, and tantalum), when they are produced in a comparatively pure state at reasonable costs. They will be able to be extracted in bulk mixtures from fission products taken from the many power, propulsion, testing, and research reactors going on-line in the next 10 years.

Neutron Counting. Since neutrons do not interact with electrons, their direct measurement is not possible with conventional sensing devices predicated on ionization such as Geiger tubes and ion chambers. Their detection is based more on the secondary effects resulting from their intermediate interaction with other substances. The recoil of nuclei of certain light elements, notably boron, after being struck with neutrons produces ions which can be easily detected. The requirement for more precise slow and fast neutron sensing elements is bound to increase and with it applications of neutrons in such diverse modes as have been suggested under activation analyses.



Courtesy of Los Alamos Scientific Laboratory

Fig. 12. Counter tank for external detection of minute levels of human body or food gamma-producing radioactivity using 108 two-inch diameter photomultiplier tubes surrounded by five-inch thick lead shield.

A neutron generator tube as simple as an X-ray tube would have hundreds of uses and is a possibility in the next year or two based on work initiated by oil companies as early as 1950.

Process Control. The use of radioisotopes in process control has certainly only begun. The concept of thickness gauging is now more than 20 years old. Certainly other applications in the industrial control realm will soon come to the forefront and become established as dependable instruments as the "beta gauge" has already done. The vibrating reed electrometer, for example, has been so improved for use as a rugged sensing device in the last 2 or 3 years that several commercial models are now available with potential for more reliable industrial sensing elements. The Ohmart cell, which relies on effect of gamma radiation to change contact potential between dissimilar metals for sensing voltage, is another example of a promising sensing device for industrial process control.

Medical. Little has been said of the important medical uses of radioisotopes thus far. This subject has been well covered in the press. Future medical applications will be greatly enhanced for therapeutic work by increased availability of large sources previously mentioned and, even more noteworthy, by low-level counting techniques which will attract much broader diagnostic uses. Some 1,800 hospitals and clinics in the United States use reactor-produced radioisotopes regularly. In addition to the therapeutic and diagnostic uses is the ever-expanding interest and application of radioisotopes in medical research aimed at finding the causes of various diseases and physiological disorders. The diagnosis of hyperthyroidism and its treatment with

Courtesy of Nuclear-Chicago Corporation

Fig. 13. Small, lightweight radiation scintillation detector incorporates sensitive photomultiplier tube and electronic circuitry in 1-inch diameter probe. Instrument is being used to locate concentrations of radioactivity in thyroid gland during surgery.

iodine-131 is as well established today in medical use as is the beta gauge for controlling sheet thickness. In fact, I-131 thyroid uptake is used in many hospitals in lieu of the basal metabolism rate test as a routine diagnostic procedure for determining general body functioning. It is now perhaps time in the cycle for other medical uses to grow to as equal importance as that of I-131 in thyroid work. (See Fig. 13).

Basic Research on Radiation Effects. It should be noted carefully that some 50 years of free basic research took place before important industrial and even medical applications of radiation became established. A balance or norm between basic research and practice is not yet apparent in the nuclear field probably because of the overriding effect of the wartime atomic program and the postwar period of secrecy and isolation until about 1954. Applications of radioisotopes are currently being developed through an empirical approach with all too little being known about the basic physical changes such as those which take place on the interaction of the several types and energies of radiation with matter.

Radioisotopes are now readily available to science and industry. Their profitable application will certainly continue unabated at a linear and perhaps even at an exponential rate through the decade of the 1960's. This present harvest of nuclear benefits to world economy and well-being has been stimulated to a degree by the sudden and somewhat unnatural postwar release of the accrued momentum of prior years of research.

It is essential now, however, to continue and even step up basic work on such subjects as the interaction of radiation with matter and the new world of subatomic particles, in order to provide a reservoir of new scientific discovery for ultimate application to the problems of the second and third decades ahead. To accomplish this will require recognition of the need and extraordinary effort in the form of careful long-range planning and budgeting by both governmental and industrial leaders. But, if the past benefits (only a few of which have been described in this review) are any criteria, the economic reward can probably be counted on to far exceed the cost of such continued basic investigation.

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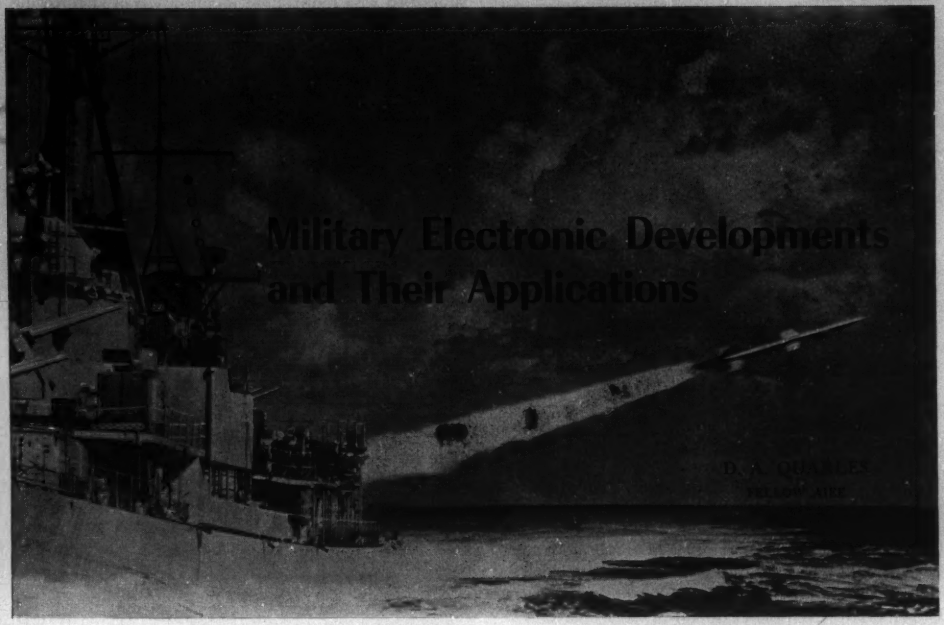
Military Electronic Developments and Their Applications



Terrier Missile being fired from USS Gyatt (DDG-1). Official Photograph, U. S. Navy

TWENTY-FIVE YEARS AGO, the military application of electron-tube devices was limited mainly to radio communications. Now electronics plays a vital role in practically every offensive and defensive weapon that our armed forces use. It provides the vast and complex network of early warning, intelligence, and command communications we must have so that, if required, our powerful defensive and retaliatory forces could spring into action in minutes.

The magnitude of this growth was indicated in a survey made recently by the Electronic Industries Association which showed that the total cost of military electronics research, development, and production purchased from industry in 1957 was $3.6 billion, slightly over 50 per cent of the entire output of the electronics industry. The 1957 bill is 36 times the total expenditure for military electronics in 1941, and it is substantially greater than the cost of producing military electronics devices during the peak year of World War II.

A review of the technical history of military electronics reveals that this rapid expansion was not so much the result of single inventions or individual technological breakthroughs as it was the systematic application of a great many advances in electronic components, circuit techniques, and engineering methods. In selecting some of the individual developments that exerted the greatest influence on the advance of military electronics, one would certainly include the magnetron, the shock-resistant subminiature tube, semiconductor devices, subminiature equipment construction, the fundamental logic of the digital computer, the discovery of tropospheric and ionospheric propagation, and the demonstration of radio echo-ranging or radar principles.

A detailed account of all the military applications of these and other technological gains during the past 25 years would be much too long for this article. So I will review the developmental growth in only a few of the areas of electronics that had the greatest impact on the conduct and outcome of World War II and have continued to exert a major influence on postwar progress in weapons and weapons systems. I will also discuss briefly some of the engineering and management problems accompanying the radical evolution of weapons systems. Finally, I will hazard a few predictions concerning the future of electronics in military operations.

RADAR

THE DEVELOPMENT of radar represents one of the most important technological advances in military history. Not only did it critically affect the outcome of World War II—it is today a fundamental component of our entire defensive and offensive capability.

In view of its important role in our total military strength, radar has been the subject of more research and development effort than any other area of military electronics. As a result, improvements in radar capabilities have been fantastic.

An infant at the beginning of the war, radar developed at a phenomenal speed. Before the war ended, this

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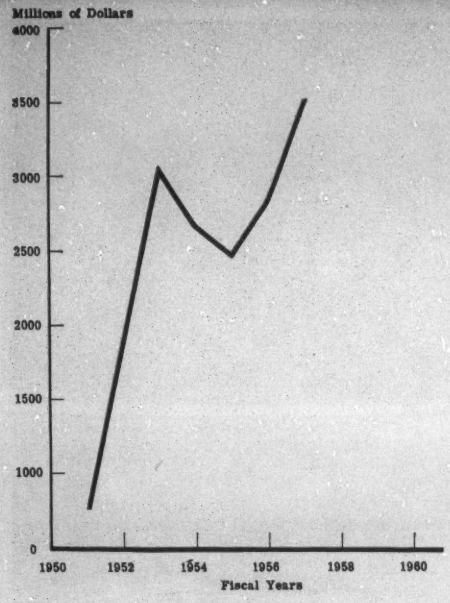


EIA, Electronics Fact Book, 1958, page 15

Military electronics expenditures for research and development and major procurement excluding military assistance.

invaluable military device had been purchased in quantities costing close to $3 billion. The best information available indicates that United States industry at the war's end was producing radar equipments at a rate of approximately $100 million a month.

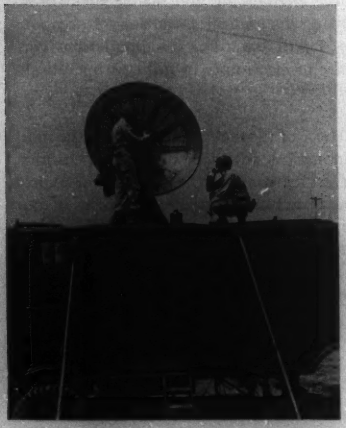
The speed of radar development during World War II has never been equalled in the history of science and engineering. British and American laboratories supported by a tremendous mobilization of engineering talent from American industry, made such a concentrated joint attack on radar development that well before the end of the war it was being used effectively for aircraft, surface-ship and submarine detection, for air and surface navigation, for controlling guns and bombs and, surprisingly, for guided-missile control. The technical gains associated with this program are greatly to the credit of the Nation's scientific, engineering, and industrial capabilities.

As great as the technical advances were during the war, we should not be misled into thinking that the development of radar has not progressed in the last 12 years. True, there have not been as many fundamentally new techniques developed, but the capabilities and versatility of radar systems have advanced tremendously.

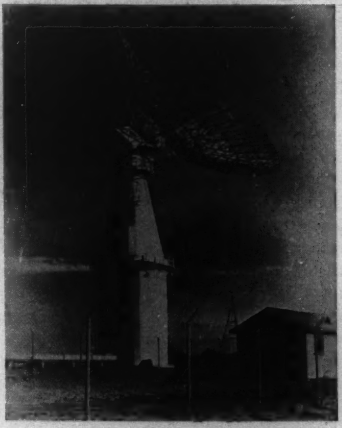
The great advances in speed, altitude, and maneuverability of manned aircraft since the end of World War II, together with the advent of the guided missile, have placed requirements on radar performance which, in some instances, are several orders of magnitude above that of the best radars in existence or under development at the close of the war. Output powers have increased by a factor of at least 40. Antenna dimensions have increased tenfold. Tracking-radar precision has improved by more than an order of magnitude. Pulse lengths as short as 0.01 microsecond are now in use, compared to the 1 to 2 microseconds of World War II equipment. The combined result of narrower beam widths and decreased pulse lengths has enormously increased target discrimination.

The pulse-doppler principle for obtaining both range and velocity measurements, which was an object of laboratory experiment during World War II, is now incorporated in operational systems for the control of guided missiles. Rapid electronic scanning methods have become an operational reality owing to the development of broad-band receiving and power tubes such as the traveling-wave tube. Great improvements incorporated

U. S. Army Photograph



U. S. Air Force Photograph



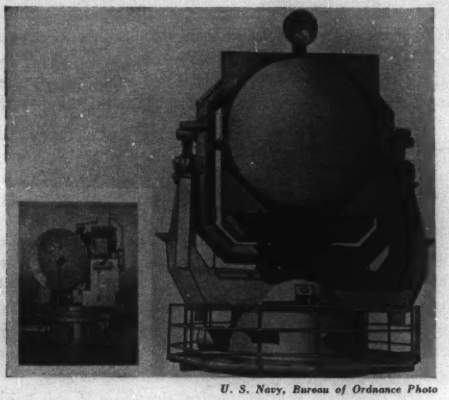
The versatility and capability of radar are illustrated by the Army's *SCR-584* mobile set (*left*) which automatically provided range, azimuth, and altitude of airborne targets and the 84-foot antenna (*right*) at Millstone Hill radar site, which is mounted on a 90-foot tower and weighs 90 tons. This radar set is used for tracking moon-probe vehicles.

in the data-processing parts of radar systems make it possible to obtain more information on target motion in shorter time intervals.

Because of the continuing work in this important area of military technology, thousands of radars representing scores of different types are now performing vital functions in the defense of this continent. Long-range surveillance radars in the Distant Early Warning (DEW) and Pine Tree lines can now detect any enemy bombing raid that penetrates our northern frontiers. Detection radars are carried in aircraft guarding the seaward approaches to our continent—radars with greater detection ranges than the best ground-based radars that operated during World War II; long-range search radars installed on Texas Towers and in picket ships far out at sea watch continually for unidentified aircraft approaching our continent. Hundreds of capable surveillance radars are in operation to direct interceptor aircraft and long-range, surface-to-air guided missiles against any aircraft attacking this continent.

U. S. Air Force Photograph

U. S. Air Force's off-shore radar station, known as a Texas Tower, which is used for early warning of aircraft coming in from the sea.



U. S. Navy, Bureau of Ordnance Photo

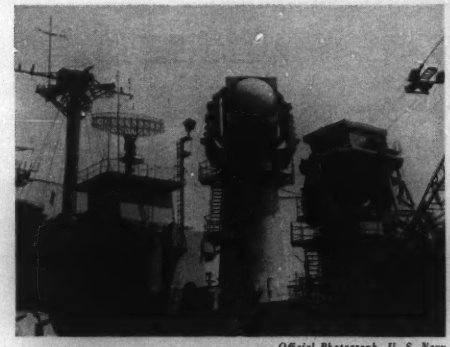
Comparison of 1948 gun fire control director (*left*) and 1958 missile control director. These units are shown to approximately the same scale.

Our force of powerful strategic bombers is equipped with modern radar devices for navigation and bombing that incorporate the most advanced principles of radar and data processing. These radars can guide our bombers to any objective in the world and direct our weapons to their targets with precision. Our modern interceptor aircraft also carry radar devices for navigation, target acquisition, and control of gun and missile armament that can perform with tremendously improved range, accuracy, and reaction time.

Operating on land and on naval vessels, our very precise weapon-control radars, with ranges and accuracies many times better than the World War II fire-control radars, direct guided missiles such as Nike–Ajax, Nike–Hercules, Hawk, Terrier, and Talos. Radar devices—active and passive, pulsed and c-w—provide accurate terminal guidance for such missiles as Bomarc, Talos, Falcon, and Sparrow.

The U.S. Army ground forces are using many varieties of radars to locate mortars and artillery, to control field antiaircraft guns and missiles, and for battlefield surveillance and location of personnel.

This brief description of the excellent radars that carry on the many functions of air defense, ground and surface warfare does not complete the radar story. We have, in the research and development stage and under actual construction, radars of an entirely new "breed"—radars for defense against an attack by ballistic missiles and radars for satellite tracking. These devices truly represent an extension of the known radar art. Although I cannot discuss in detail the characteristics of these radar developments, I can say that they will extend radar performance yet another order of magnitude beyond that of our operating radars. For example, to obtain the detection range of several thousands of miles



Official Photograph, U. S. Navy

Shipboard installation of missile control directors. Gun fire control director antenna is on second superstructure, the level platform at the left center of the picture. Search antennas can be seen in the background.

required of the ballistic-missile early warning system that is now being constructed, the peak radiated power will be measured in tens of megawatts, and antenna dimensions will approximate the size of three football fields standing on edge, end to end.

Now let us look at some of the other areas in military electronics that played important roles in World War II and are still vital to our current weapon developments.

THE PROXIMITY FUZE

THE INITIAL DEVELOPMENT of the proximity fuze was sponsored in 1940 by the newly established National Defense Research Committee. To expedite the development, a two-phase program was undertaken. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington (later succeeded by the Applied Physics Laboratory of The Johns Hopkins University) commenced the development of fuzes for gunfired antiaircraft artillery shells under the guidance of the U.S. Navy. The National Bureau of Standards, under Army sponsorship, confined its development work primarily to bomb, rocket, and mortar-shell fuzing, with primary emphasis on ground targets.

From the beginning, there was close collaboration and transfer of ideas among these participants. Throughout World War II, work on the two phases of development was mutually complementary, and information on techniques of measurement, design, and test was freely interchanged. As a result, effective proximity fuzes were available early in the war.

Perhaps the most difficult, as well as the most remarkable, technical development in the joint proximity fuze effort was the provision of a subminiature electron tube that could reliably withstand the shock of gunfire and remain effective. It is interesting that, as far as we know, no other nation had a major project during the war that was directed toward developing proximity fuzes for rifled artillery. Probably their technical people considered it impractical to try building a fragile vacuum tube that could withstand the shock of gunfire. The fact that we did build one and they did not gave us an important advantage in many battles of World War II in both Europe and the Pacific.

Official Photograph, U. S. Navy

A typical scene in the radar plot room, Combat Information Center, in 1944, aboard an aircraft carrier.

Perhaps one reason we held this advantage through the entire war period was the care with which we guarded our secret. Even when proximity fuzes were available in quantity for many weapons, their tactical use was closely restricted. Before 1944, the new fuzes were used only in situations where the shells would fall into the sea to prevent the enemy from recovering them. They were used for the first time over land in 1944 in the defense against the buzz-bomb attack on England. Finally, they were used very effectively as a tactical surprise in the Battle of the Bulge. Security was so well maintained and the timing of the fuze's employment was so effective that the enemy did not discover the nature of this new and devastating weapon until the war was over.

Today, the proximity fuze is considerably improved, particularly with respect to its vulnerability against countermeasures and its effectiveness at low angles of attack, and it is still being used in many of our weapons. Moreover, some of the sophisticated elements in our most modern weapon systems are based on the fundamental principles and the rugged components developed in the wartime fuze program.

DATA-PROCESSING, DISPLAY, AND CONTROL SYSTEMS

THIS AREA OF ELECTRONICS has seen the most extensive development and application of new technology since the end of World War II. Data processing, display, and control are the functions that must be performed between the outputs of various information-gathering or sensing elements of a system and the actual assignment of a specific weapon or weapons to selected targets.

Early in World War II, tactical doctrines in this field were based on the old methods of detecting targets and directing weapons by optical means. As soon as search and fire-control radars came into use, it was found that an operator observing a target on a search radar could not telephone to the man at the fire-control radar fast enough or give him accurate enough information to get the fire-control radar on target.

As the cathode-ray tube plan position indicator became available, radar target-designation devices were developed that would transmit the range and bearing of a target picked up on the search radar directly to the fire-control radar by synchronized signals. These rather crude target-designation devices represented the first data-processing, display, and control systems. They allowed a single individual to survey the tactical situation, identify the targets to be taken under fire, and direct specific fire-control systems to engage the assigned targets.

One very significant step in this direction was the Navy's development of the Combat Information Cen-

International Business Machines, Inc., Photo

Components of the SAGE system with surveillance room shown in center of group.

ter. This system centralized displays from all of the ship's radars, sonars, and optical devices, making it possible for the ship's commander to maintain complete combat control in both air and surface battles.

As the air and surface battles grew more complex, the Combat Information Center was expanded to handle tactical information from other ships of the task force and from radar-equipped aircraft. The task-force commander thus had the benefit of a centralized information-gathering, processing, and display center which greatly improved his capability for commanding the naval force. But even this system became badly overloaded later in the war under conditions of saturation air attack.

After the war, a radical advance in the performance of aircraft was prophesied, and the guided-missile era was beginning. Estimates of future weapons, coupled with experience gained in the war, convinced military planners that a force commander must have the aid of more complete automaticity in the processing and display of data and in the assignment and control of weapons; otherwise, he could no longer effectively direct short-reaction-time weapons under conditions of high-speed air attack. Man could not assimilate the amount of data needed for an accurate appraisal of the tactical situation and make sound command decisions fast enough to be effective. His capabilities had been outstripped by the great strides in weapon performance. It was this realization that stimulated the many developments in automatic data-processing, display, and control systems, commonly referred to in the late 1940's as the advent of "push-button warfare."

Several imaginative study and development programs in air-defense data processing and control were initiated by the military departments immediately at the end of World War II. In 1946, the Navy began a study program leading to the development of a system that would automatically track air targets from the output of search

radars, automatically determine the relative threat of the targets being tracked, and automatically assign targets to the ship's antiaircraft guns on a priority basis. This complex but effective system was completed and installed on a cruiser for evaluation. The system's concept proved to be satisfactory, and its techniques and components served as the basis for the effective weapons-direction system for all the Navy's guided-missile ships.

As the Navy began this development, the Army Signal Corps Laboratories started to develop a similar system for directing antiaircraft gun batteries. Known as Project *414-A*, this system was the basis for later developments: the *AN/FSG-1*, or Missile Master, which is now used in the direction of Nike–Ajax and Nike–Hercules missile batteries at permanent defense installations around major cities, and the *AN/MSG-4* system for the direction of mobile missile batteries in the field Army.

Another important milestone was passed in 1947 when the Office of Naval Research initiated a project to develop a digital computer that would process radar data received over telephone lines, generate a visual display of aircraft tracks, and automatically direct an aircraft to intercept the target. Early in 1951, this computer, called Whirlwind I, successfully demonstrated that a digital computer could perform these important military functions. From this proof of feasibilty emerged the largest, most complex—and incidentally the most expensive—system-engineering and production program in the history of electronics. Designated SAGE (Semi-Automatic Ground Environment), this system development was sponsored by the U.S. Air Force. Today an integrated air-defense capability is being established by the installation of SAGE systems throughout the continent. By a complex network of radio and telephone communications, these systems connect all the hundreds of air-surveillance radars and generate direction and control commands for interceptor aircraft and surface-to-air guided missiles.

At present, other automatic data-processing, display, and control systems are being developed for several tactical applications. These systems are being designed on the general principles that were incorporated in SAGE. Fortunately, progress in digital-computer technology and the application of solid-state devices is making it possible to build these complex systems to occupy a much smaller volume of space, even to the point of airborne systems.

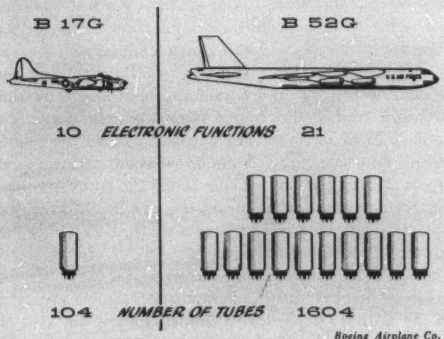


Illustration of electronics growth from typical World War II bomber B-17G to a modern B-52G.

AIRCRAFT ELECTRONICS

BEFORE WORLD WAR II, aircraft carried little in the way of electronic equipment aside from voice or code communications, although, as I mentioned before, some of our aircraft were equipped with British ASV search radars as we entered the war.

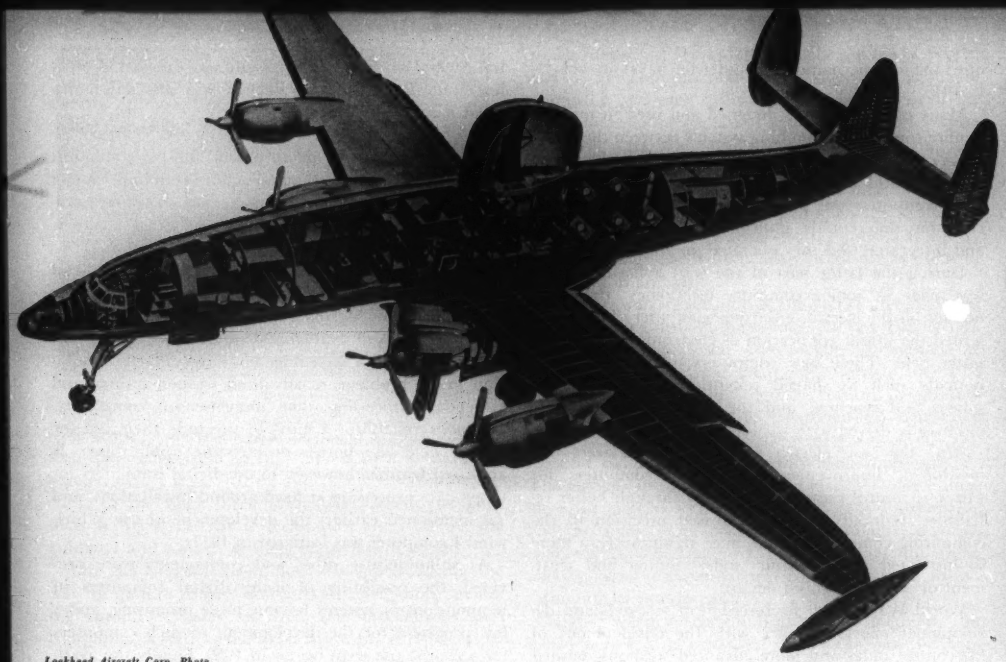
In the early part of the war, aircraft armament was controlled optically with the lead-computing sight, and bombing was accomplished very effectively in periods of good visibility with the Norden bombsight. As the war progressed, our forced draft electronic development and production programs started to supply improved radars for search and air interception (AI). Fire-control computers were developed to work in conjunction with the AI radars so that the aircraft guns could be fired by radar control.

In 1943, service aircraft received the first radar-controlled bombing system, a modified airborne search radar "married" to the computing elements of the Norden bombsight. This system was very simple compared to the standards of today, but it worked quite well and played an important role in the war.

Before the fighting was over many new types of airborne electronic devices were coming into service and many others were being developed. Electronic navigation devices such as shoran and radio beacons became operational. New and improved airborne intercept AI radars and radar bombing systems that were substituted for earlier versions provided much greater operational effectiveness. Our heavy bombers in the European Theater of Operations carried radar-jamming equipment during the war's last months to protect them against radar-controlled antiaircraft gunfire.

Many of the airborne electronic equipment developments were reoriented after the war to meet anticipated requirements of the future. Here again, the sudden upsurge of aircraft performance made it impossible for the pilot to fly the aircraft, operate the complex fire-control system, and at the same time use his communication, identification, and navigational aids. The consequence was, of course, a trend more and more toward the development of completely automatic operation of the systems for fire control, bombing, navigation, and communications.

One cannot deny the necessity for taking this approach to interceptor and bombing control, but it has certainly added immensely to the complexity of the airborne electronic equipment. For example, the number of electron tubes in an interceptor aircraft has gone from 180 in World War II to 1,000 tubes and 4,000 semiconductor devices in our present *F-106* all weather inter-



Lockheed Aircraft Corp. Photo

Electronic components installed in the Airborne Early Warning aircraft are illustrated in this cutaway view.

ceptor. Similarly, the electronic equipment in a World War II bomber employed 104 electron tubes, compared to 1,604 tubes plus a very large number of semiconductor devices in the *B-52*. In the next generation of bombers, now in development, the electronic systems will be even more complicated. It is estimated that at least 2,400 electron tubes and 4,100 diodes and transistors will be used.

These new airborne systems involve many different types of newly developed electronic devices: several kinds of radars, solid-state digital computers, communication systems operating at ultrahigh and high frequencies, ground-to-air data links, countermeasures equipment that can automatically search and jam, and navigation systems employing doppler, inertial, and stellar tracking principles.

Unfortunately, the high cost and complexity of these new airborne electronic systems cannot be avoided if their performance is to meet the operational objectives that stem from the new aircraft speeds and military missions.

The airborne early warning and control aircraft (AEW/C) plays another extremely important part in air defense. This aircraft (mentioned briefly in my comments on radar) is truly a flying electronic storehouse; the production cost of the electronic equipment it carries is higher than that of the aircraft itself. Its function is to detect enemy aircraft beyond the ranges of the coastal surveillance radars and to direct our long-range interceptors against those targets at points far beyond our shores.

The AEW/C systems evolved from the basic airborne early warning system development that was undertaken in the latter part of World War II. Although the AEW development came too late for widespread use in the war, the soundness of the concept was established, preparing the way for our present highly advanced systems.

ELECTRONIC COMPUTERS

COMPUTERS, in one form or another, have had a vital role in military operations since Hannibal Ford devel-

Official Photograph, U. S. Navy

Air Force AEW aircraft operating in conjunction with Navy radar picket escort vessel.

oped the first mechanical computer for naval fire control in 1915.

Many computers were designed and used in military gunfire control and bombing systems between the development of this first mechanical computer and the beginning of World War II. The computation in all of these early computers was performed entirely with mechanical cams, differentials, multipliers, component solvers, and integraters and they operated on analog principles.

During the latter part of the war, a basic advance was made in analog computer technology: the introduction of the electric/electronic computer. This represented the initial application of electronics in the computer field. These new computers used electric components such as shaped potentiometers, electric resolvers and synchros, and the servomechanisms were electrically driven with vacuum-tube amplifiers.

After the basic electric analog principles were first developed, improvements in analog computers for weapons control came about largely through better reliability, reduced size and increased precision of the computing components, and, most significantly, a more sophisticated and scientific understanding and treatment of servomechanism design.

World War II and its forced-draft research and development effort, together with the development of fire-control radar and more advanced weapons, pushed computer development forward rapidly. Before the war was over, guns, aircraft, bombs, torpedoes, mines, rockets, and even guided missiles were being controlled with the aid of analog computers.

As mentioned before, between World War II and the beginning of the Korean conflict in 1950, the military services embarked upon a new era of weapons development generally based upon the kind of war that might be fought in 1960. Development programs that offered only marginal improvement in performance over World War II devices were discontinued, and emphasis in air defense was placed on weapons capable of engaging targets of near-sonic or supersonic velocity in mass saturation attacks. Guns gave way to guided missiles; manual control of interceptor aircraft was considered obsolete, and the lethality of nuclear weapons was multiplied many times over.

Official Photograph, U. S. Navy

The guided missile cruiser USS Boston with its surface-to-air Terrier missiles ready for launching.

Requirements for computers to control these advanced new weapons and to process the large amounts of data necessary for command actions could not be met by the application of existing analog computer techniques because they lacked the necessary speed, accuracy, and capacity.

By 1948, the general-purpose digital computer had been developed under military sponsorship to meet the requirements for high-speed, accurate processing of data in connection with ballistic tables and information correlation. Although these huge machines offered the solution to the problems of advanced weapon control and target-data processing, their immense size, complexity, and poor reliability seemed to preclude their use for mobile field, shipborne, or airborne applications. It appeared feasible, however, to use digital computers for target-data processing at fixed ground installations, and (as mentioned earlier) the development of the Whirlwind I computer was initiated in 1947.

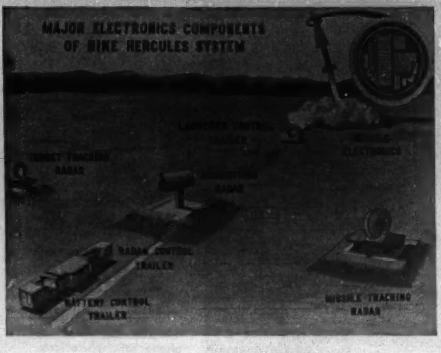
As subminiature tubes and components were provided, the possibility of using digital computers in weapon-control systems became more promising, and a few programs for the development of such computers for airborne use were begun in 1950. Finally the availability of reliable transistors in quantity made it possible to obtain the reduction in size, weight and power requirements, and the improved reliability that was needed to make the digital computer a practical device for virtually all weapon-control functions.

Today, digital computers are in operation or under development for many military applications, not only for the processing of target data and weapon control, but also for expediting logistic operations and for use as an essential laboratory tool in the design of complex missile and aircraft weapons systems. They have also become an important and rapidly expanding element in our civilian economy. In the past few years, the combined military and commercial requirements for digital computers have expanded so rapidly that the digital-computer segment represents a major portion of the total electronics industry.

GUIDED MISSILES

GUIDED MISSILES were used operationally for the first time when the Germans bombarded London with the famous *V-1* buzz bomb in 1944. Later, *V-2* ballistic missiles were launched in heavy raids against London and the coastal cities of England.

During the 15 years since the initial employment of these early guided weapons, the technology has been developed to such an advanced state that the guided missile has become one of the most important military weapons. Armed with high-explosive warheads and with nuclear warheads having yields ranging from a few kilotons to those counted in megatons, guided missiles in our current weapons stockpiles, in advanced stages of engineering and in early production, are designed for a



wide scope of defensive and offensive applications. In size, they range from small weapons such as the Sidewinder, which is carried on supersonic interceptor aircraft, to the huge intercontinental ballistic weapons such as Atlas. Electronic techniques are vital for the guidance and control of these many missile types.

The fundamental techniques developed during the war for gunfire control and aircraft navigation, including autopilots, radar, infrared, servomechanisms, and computers, served as the foundation for early developments in missile guidance systems. Reviewing the history of guided missiles from a technical viewpoint, we find even now that most of our guidance systems for missiles are extensions of those basic techniques and principles of fire control and aircraft navigation. But we have devoted enormous amounts of time, effort, and money to the job of raising the performance of these systems, reducing their size, weight, and power consumption to the point where they can be fitted into missile airframes, and designing the associated components and devices to withstand the shock and vibration and other unique environments of missile launching and flight.

We now spend well over $1 billion a year to develop and produce the electronic guidance devices for these missiles, almost one third of the total cost of all military electronics. We have many different types of guidance systems, from the relatively simple infrared seeker used in the Sidewinder air-to-air missile to the complicated and extremely precise radar command systems of the Nike–Hercules and the combination command and beam-rider systems that control the Talos missile.

Our present operational missiles—the air-to-air, surface-to-air, and air-to-surface types, as well as the long-range surface-to-surface ballistic weapons—now employ among others the following guidance techniques: radar homing, command, beam riding, and mapping; wire guidance; pure inertial, radio inertial, and star-tracking navigation.

COMMUNICATIONS

Communications really provided the requirements and incentives that built the foundation for the electronics industry. Even as late as the beginning of World War II, an electronics man was considered to be a communicator, and early military radars were given to the communicators for operation and maintenance. Despite this early start, communications advanced during the war years mainly by vigorous exploitation and adaptation of known techniques. Probably the most impressive gains were made in developing components to use the vhf spectrum effectively with small, lightweight equipments that were particularly adapted for use by the field Army and in aircraft.

The new warfare techniques and tactics that appeared —the blitzkrieg in land operations, the fast-moving task force employing closely co-operating antisubmarine warfare and air-defense tactics, the greatly increased numbers of aircraft requiring traffic control, the ground-based, air-intercept control technique—all demanded more flexibility in handling the greater volume of traffic than the old procedures and equipments could provide. The obvious answer was to use vhf tactical circuits; these have the partial security of line-of-sight transmission and, as many more channels are available, separate channels can be assigned for individual functions, making possible faster tactical communications with a minimum of interference.

High-frequency communications throughout the world were greatly expanded during the war. Teletype equipment came into common usage to replace code and copy operators on heavy traffic tactical and logistic circuits, and semiautomatic devices were used regularly to speed the encoding and decoding processes. Although wartime communications were often a source of irritation to military commanders, they were seldom a tactically limiting factor. These delays, caused by manual message handling and relay, the reliability factor of the high-frequency circuits and the slow data rate of the low-frequency or vlf circuits, were all acceptable because the procedures being used had been designed to function with them.

The postwar trend toward higher-frequency tactical circuits continued with the opening of the uhf band through the development of new components and techniques. This again permitted more circuits, as well as circuits of wider bandwidths, for command control. More significant during this period, however, has been the development of ionospheric-scatter and tropospheric-scatter techniques, which have altered the operational concept of the limiting principle of maximum usable frequencies on many long-range communications circuits. Although much of today's long-range communications depend upon high-frequency circuits, the amount of traffic carried on scatter circuits is increasing almost every day. Using bandwidths that can carry hundreds of multiplex channels simultaneously, these new communication links span vast distances of undeveloped land areas, and are operating with reliability almost the equal of cable circuits.

During and after World War II, a new tool was developed for communications design which was known as "information theory." Gradually, techniques for ap-

Three types of DEW line antennas are shown at this auxiliary station. The two small antennas, back-to-back on tall tower, are for aircraft alarm system. The "bubble" houses long-range aircraft detection radar, while the "dish" antennas provide lateral radio-telephone communications.

U. S. Air Force Photograph

plying this theory to military operational situations and equipment-development programs came into being. As the pressure for expanded communications grew stronger, the available communications were used more fully through these techniques, which guided designers in removing communications redundancy.

Today, we are turning more and more toward binary data streams and the elimination of language redundancy. It appears that a far greater portion of all military communications will soon be transmitted in digitalized form, whether the terminal receiving equipment is a computer, a message writer, a picture display, or a sound transducer. Supporting and directly associated with this trend are developments that have led to automatic crypto devices and techniques for automatic circuit and message switching. These advances combine to permit the transmission of intelligence data and commands in a fraction of the time that was needed before. Applications vary from complex, specialized, self-contained systems, such as SAGE, to the more mundane business of day-to-day record keeping in a vast logistics supply network.

The development of techniques for more versatile and stable frequency control led to the design of transmitters and receivers that could be switched from one channel to another. This advance, which virtually eliminated the vagaries of tuning, made it possible to shift communications faster and more reliably to permit improved tactical procedures of new operational techniques.

The new weapons that are coming into existence place unprecedented destructive power in the hands of small military units scattered throughout the world. In these circumstances, it is difficult to conceive of a communication facility which will give the military commanders unquestionable assurance of control over their forces. As this situation develops, the pressure for tight control of these modern weapons and for rapid information gathering to use as a basis for command decisions develop with it. It is these pressures that are causing us to accelerate our communications programs continually.

U. S. Air Force Photograph

A DEW line installation on Canadian arctic border features a bubble radome housing of long-range radar and two types of tropospheric scatter lateral communications antenna: the "drive-in-theater" screen reflector antennas at left foreground and the large parabolic "dish" antennas at center and left rear. Aircraft alarm system antennas are shown in center; they are the back-to-back antennas on the tall scaffolding.

ENGINEERING PROBLEMS

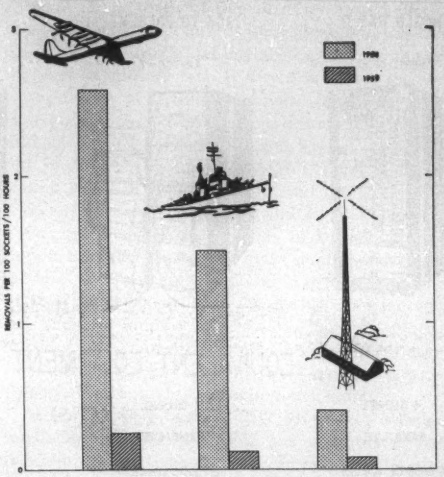
THE RAPIDLY EXPANDING use of electronics in military systems and the tremendous increases in the complexity of electronic devices have generated many new and complex engineering problems.

Equipment Reliability. The most difficult engineering problem accompanying the growth of military electronics has been to make the equipment reliable—to engineer and build the intricate electronic devices so that they can be depended upon to perform satisfactorily in a service environment and so that maintenance people at the level of technical skills available in the services can keep them running effectively.

As the United States entered World War II, we had to build our radars and other electronic equipments with components, such as vacuum tubes, that were being produced for the commercial telephone and radio industry. Also, the mechanical designs for military devices closely resembled those used commercially. It was soon discovered that these components and design methods were not good enough for military equipment that had to operate continuously under the sometimes hard environments of service. For example, the shock of naval gunfire would make shipboard radar and other electronic equipments inoperative, often with serious damage. It was also found that the electronic components then available were not uniform enough or good enough to maintain the close circuit tolerances that many of the new equipments required for effective operation. As a result, radar designers generally accepted early in the war that their equipments would normally operate in service with very much lower sensitivity (around 12 db) than they demonstrated in the laboratory. But before the war ended, military maintenance personnel were so much more proficient and equipment design and components had so greatly improved that this degradation of equipment in service had been substantially halved.

Generally, the quality of electron tubes and component parts was considerably raised during the war. In an extensive program, existing tube designs were ruggedized so that they could better withstand the shock and vibration of service use. Performance specifications and test requirements were tightened to control the quality of all tubes and components for military use. Also, it was made mandatory that a manufacturer of components for military sale qualify his product through Government testing of sample lots.

As the war progressed, the electronics community learned a lot about the relationships between equipment design and service reliability. From a sort of "cut-and-try" process, shock and vibration mounting and structural design developed into a predictable science. Testing in the laboratory was soon recognized as an essential part of engineering design. From these tests, which took place in both Government and contractor laboratories, much was learned about how design factors affect the reliability of equipment. In 1945, the services were getting electronic equipments that were considerably more reliable and somewhat easier to maintain.

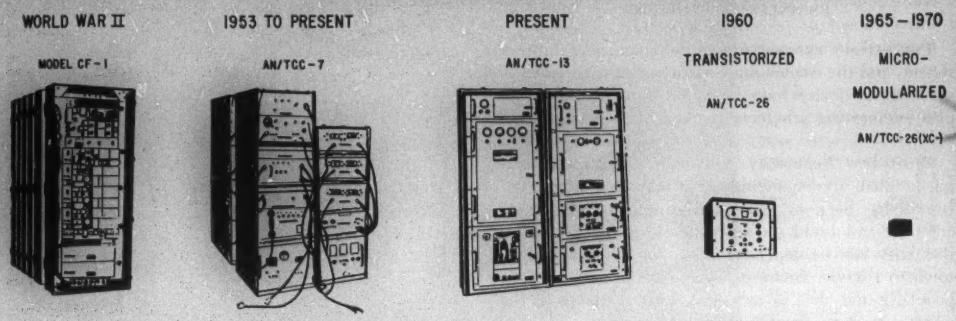


Courtesy of Arinc Research Corp.

Improvement in receiving tubes, used in aircraft, shipboard, and shore applications, is illustrated by differences in removals from sockets in 1954 and 1959.

After the war, the increasing complexity of military electronic devices tended to offset the reliability gains that improved components and engineering methods had achieved. Further adverse effects arose from short cuts that were taken in engineering and testing because of the urgency for completing weapon-system developments.

For 5 or 6 years now, the military departments and the Office of the Secretary of Defense have become increasingly aware of the importance of emphasizing equipment reliability in our weapon programs. A comprehensive study was made recently by the Advisory Group on Reliability of Electronic Equipment, which was set up in the Office of the Secretary of Defense to determine the factors associated with specifications, design, manufacture, testing, maintenance, and procurement practices that have a direct bearing upon reliability. As a result, many new engineering procedures were developed and methods determined for specifying reliability in quantitative terms, prediction through mathematical computation and measurement at various stages of development, engineering, and production. The reliability art is being rapidly brought into the category of engineering science. The military departments are now using many of these new procedures and methods in their development and production programs. Moreover, many of the industrial concerns that contract for system development have established special organizations solely to assure product reliability. As a result of this fairly recent emphasis on reliability there has been



EQUIVALENT EQUIPMENT FOR 23 CHANNEL CAPACITY

4 CHANNEL	12 CHANNEL	23 CHANNEL	23 CHANNEL	23 CHANNEL
RADIO/LINE	RADIO/LINE	RADIO	RADIO	RADIO
6 EQUIPTS (24 CH)	2 EQUIPS (24 CH)	1 EQUIPT	1 EQUIPT	1 EQUIPT
2880 LBS	1492 LBS	1200 LBS	65 LBS	3 LBS
123 CU FT	51.4 CU FT	40 CU FT	2½ CU FT	0.07 CUFT

Courtesy of U. S. Army Signal Corps

Miniaturization of multiplex terminal equipment since World War II is illustrated by decreasing sizes of units.

an important improvement in the quality of military systems.

Miniaturization. This noteworthy area of engineering was born of the growing demand for smaller and lighter electronic equipment to be used in guided missiles and high-performance aircraft, in which a very high premium is placed on space and weight. The many changes in components and design practices since the war have resulted in successive reductions in the size, weight, and power consumption of electronic equipments.

The development of the miniature electron tube and other component parts of comparably reduced sizes brought about the first significant reduction in equipment size and weight—about three to one. The next major reduction came when subminiature tubes and electronic parts, together with printed circuits, were made available. These made it possible to get a further 300 per cent reduction in volume and to lower the weight by at least 50 per cent. With the new subminiaturized electronic equipments, all of the necessary electronic system functions could, for the first time, be included in a high-performance aircraft without seriously degrading its flight performance.

Today, much of our newest electronic equipment is being designed around the transistor, which permits yet another decrease in equipment size and weight. In some cases, this is as much as a 20-to-1 reduction over the previous subminiature-tube construction. Power-supply requirements are also substantially lower in the transistorized equipments, and we are confident of achieving a further substantial improvement in system reliability.

Modular Construction. This represents another real engineering advance that has been made recently in the design of military electronic equipment. Instead of grouping a large complex of functional units on a single chassis, modular construction breaks the functional units at a lower level of assembly and packages these simpler assemblies as plug-in modules. This has many advantages in production, logistic supply, and maintenance. Moreover, equipments can be assembled to fit the unique space configurations of different vehicles while the same basic modular subassemblies are retained. Field-maintenance efforts are lessened because equipment failures can usually be remedied by replacing the defective module without having to locate and replace the individual defective component parts.

MANAGEMENT

CONCEPTS OF WARFARE and military preparedness have been radically changed by the development of new weapon systems that were made possible by the rapid technological advances since 1945 in electronics, aerodynamics, propulsion, and most importantly, in nuclear explosives. World political tensions created in the years since the war have also contributed to these changes. Among the consequences are significant alterations in the processes and objectives of management in all phases of military operations—from research and development to the training and tactical employment of our armed forces.

In the 20-odd years between World War I and the outbreak of the second World War, the people of this country, apparently unconcerned with their military

establishments, gave them little financial support. So this Nation faced the tremendous task of building up its armed strength fast enough to stand firm in a conflict with nations that for years had been planning and preparing for war. We had to mobilize our scientific capabilities to undertake a tremendous military research and development program; our industrial capacity had to be turned from the manufacture of consumer products and expanded rapidly to meet the demands of wartime production; the military departments had to recruit, or draft, and train millions of soldiers, sailors, and airmen; and we had to establish lines of communication and supply that we needed for the conduct of a long war in two theaters. Fortunately, in its early stages the war's pace was slow enough that there was time to do all these things effectively.

Today, we have a tense cold-war situation, and the communist nations are rapidly building up an arsenal of powerful offensive weapons; therefore, we must keep our defensive and retaliatory forces constantly ready to go into full action in minutes, if necessary. At the same time, any or all of the three branches of our armed services have to be ready for effective deployment in any situation short of a general war that requires military action.

In the evolution of this state of military preparedness, emphasis has steadily shifted from the maintenance of large forces to reliance on fewer weapons of greater striking power, and our military ability to deter a general war—or to be immediately effective if such a war should be forced on us—is depending more and more upon advances in weapons technology. This has required that we retain our superiority in all branches of technology on which the many kinds of weapons and weapon systems are based, using the newly developed technology to create usable systems as quickly as possible. Some of our weapon systems have had to be produced on "crash" programs, because the nation's deterrent and defensive posture depends on the possession of operational weapons with capabilities equal or superior to those of a potential aggressor, not on its storehouse of scientific knowledge.

Thus, we have been forced into a continually expanding effort in military research and development—an effort that now claims the energies of 60 per cent of this country's electronic scientists and engineers. The situation has compelled us to discard some newly developed weapons that were outmoded very soon after they were ready for service; sometimes this happens even before development is complete. And every successive development of a weapon or weapon system seems to be more difficult, more complex, and generally more expensive.

In the face of rising costs, the planning and directing of this tremendous research and development effort—while staying within a military budget that does not too heavily burden the national economy—has created a management job of staggering proportions in the Department of Defense. To keep pace with the management problem, several organizational changes have been made since 1945 in the military departments and in the Office of the Secretary of Defense. The desired effect of these changes was not only to place greater management emphasis on research and engineering but, recognizing the shift in military preparedness from force readiness to superiority of technical weapons, to associate more closely the direction of research and engineering with military planning at top command levels. The most recent of these changes was the establishment of the Advanced Research Projects Agency and the Office of the Director of Defense Research and Engineering, both within the Office of the Secretary of Defense. In addition, it has been necessary to make some changes in the methods and procedures followed in program execution to keep management in step with the changing scope and tempo of military research, development, and production. One innovation that is especially worth noting is the weapon-system concept that is now being widely employed in research and development work.

As our weapons systems have grown more complicated, an intricate functional and operational interrelationship has developed between many of the major system components, and this aspect of weapons systems must be planned and developed as an entity to obtain the maximum operational effectiveness. For example, in a surface-to-air missile system such as Nike, the performance characteristics of the airborne and ground-based guidance components are so closely related to each other and to the aerodynamic characteristics of the missile structure that it would be extremely hard—perhaps impossible—to design any of these system components separately without endangering the performance of the whole weapon system. This is the reason for the present tendency to assign the entire responsibility for systems design and engineering, as well as program management, to a single prime developmental contractor. Of course, this does not mean that the systems contractor must develop and build all the components. There are at best few industrial concerns in this country that have sufficiently diversified technical know-how to undertake work in the many technologies involved in a complex missile or aircraft weapon system.

THE FUTURE

To foretell the progress that will be made in any branch of science for a long time in the future is to attempt a prediction of the ideas and inventions that will emerge from the minds of men. When we try to foresee how military technology will advance, our vision is further obscured by uncertainties in the world situation which, in the final analysis, will govern the trend of military research and development.

By every indication, electronics will continue to be vitally important to military operations, and its uses will spread even more widely as new solid-state components, much smaller and more reliable, make it possible to accomplish more difficult and intricate functions. As long as world tensions persist, defense expenditures for research and development in electronics can be expected to continue the upward trend.

Since we will probably not be buying such things as

U. S. Army Photograph

Project Score—Electronic components built into the Atlas satellite missile.

satellites, ballistic missiles, and antiballistic-missile defense systems in large quantities, it is to be expected that the research and development content of military electronics will tend to increase as compared with the production content.

Fundamentally, the military problem is to deliver destructive power against a distant target. The very rapid developments in aeronautics—and now, astronautics—and nuclear explosives has radically changed the time-and-space dimensions of the problem. One might regard electronics as man's aid in adapting himself to these changes. Radar enables him to see farther and to see more; communications, to apply control at a distance; and electronic computers, to handle the problems of logic confronting him with greater speed than the human mind is capable of.

This leads to speculation on how far this trend might take us in another 25 years. I have no doubt that the trend will continue, but there are countervailing factors. There is always some disadvantage in trying to operate by remote control. Other things being equal, we would always prefer to bring the intelligence of the operator nearer to the target objective so that human judgment may be added to the purely mechanical logic of remote control and computing systems. This, it seems to me, is why there will always be a need for the manned aircraft, even assuming as I do that unmanned missiles will become increasingly sophisticated and reliable. In the missile system, the human intelligence directing the system is back at the launching point, whereas in the manned aircraft human intelligence is present throughout a much greater part of the operation. It is only when the operating environment exceeds human capabilities that we are forced to resort to remote control, automation, and all of the other complexities of many modern weapon systems.

In military electronics, we must remember that the electronic systems on one side are competitive with the opposing ones on the other side. This is true not only in the sense that the better equipment will give an advantage to the side possessing it, but in the sense that one side, by using countermeasures, can deny the other side the effective use of its own equipment. Military electronics therefore must be regarded as a triple threat: first, as a means of producing effective weapon systems; second, as a means of denying the other side the effective use of its weapon systems, and, finally, of achieving effective operation in spite of hostile countermeasures. If present conditions of world tension continue for another quarter of a century, one must expect that the endless struggle of electronic measures and countermeasures will continue, in fact, that it will be intensified.

With these thoughts in mind, it seems safe to predict that there will be further rapid progress in improving the speed, volume, and security of communications, in remote control and in the automation, miniaturization, serviceability, and reliability of the equipment, all very greatly complicated by electronic warfare measures to secure the benefits of electronic systems to ourselves and to deny these benefits to our adversaries. Success will go to the side that is most resourceful in this technological struggle, resourcefulness depending in no small measure on a broad and deep research program in related scientific fields and on its initiative in seizing and capitalizing on technological breakthroughs.

In the quarter century ahead, activities in space beyond the atmosphere will undoubtedly play a sharply increasing role; for example, in relieving us of present line-of-sight limitations on the utilization of higher and higher frequencies. It may be that the sound of President Eisenhower's voice as it was broadcast from outer space last Christmas heralded a new era in military electronics.

Missiles, Rockets, and Space Flight

W. H. PICKERING
MEMBER AIEE

Nike-Hercules antiaircraft missile reaches target with radio command guidance system. Courtesy Douglas Aircraft Co., Inc.

LESS THAN A QUARTER of a century ago, there was no semblance of a rocket or guided missile industry; today, there exists a multibillion-dollar business employing a sizable fraction of the Nation's most skilled scientists, engineers, and technicians. This industry has brought into being, in the relatively short span of some dozen years or so, some of the most sophisticated and complex mechanical and electrical systems yet conceived by man. There exist today target-seeking missiles for military applications, and vehicles for exploring cislunar space, not to mention the highly automated ancillary devices and equipment required to support operations and missions which existed in the realm of fantasy only several decades ago.

In point of fact, the majority of the significant developments in rocketry and missilry have come about since the end of World War II and, as is now evident, efforts to advance the state of the art are currently undergoing a rapid acceleration which is attributable in part to the advent of the Sputniks. Obviously, we are still in the genesis of the space age and where it will lead us cannot be predicted with any high degree of certainty. I believe, however, that it is safe to assume that within a generation, today's accomplishments, when viewed in retrospect, may well be regarded in a light comparable to that typified by the first flying machines as compared to modern jet aircraft. This upsurge of interest in rocketry has obviously been primarily the result of its potentialities for military applications, and, until very recently, little has been done on developments specifically related to nonmilitary usage. I believe, however, that this situation will undergo considerable change in the future. Already there are indications of this as evidenced by the development of specialized rockets and, more recently, satellites and space probes for conducting scientific research of the upper atmosphere and contiguous space. I fully expect that this trend of developing research vehicles primarily for nonmilitary and scientific purposes will continue and that it will increase in scope as it becomes evident that the results accruing from the scientific exploration of space for peaceful purposes have commercial implications and applications which stand to benefit mankind as a whole. As an example of this, it is already apparent that the placing of satellites in orbit for use as relay stations in space offers means for providing world-wide communciation networks and navigational aid devices on a scale unsurpassed by anything conceived in the past.

The electrical engineering profession has, and will continue to have, a highly significant role in these new developments. It is no overstatement to say that the space age would be impossible without modern electronics, and conversely, that the electric and electronic equipment which has been developed for missile and space vehicle applications has already been responsible for a number of significant electrical advancements having important by-product usages. Missile applications have introduced new methods of fabrication for withstanding extremely adverse environmental con-

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ditions, new criteria for reliability, new standards for component accuracy, and stringent requirements for long-term operational stability. In addition, new design philosophies are emerging which involve the mircominiaturization of components and assemblies to reduce volume requirements to a scale hitherto considered impractical. These concepts apply particularly in the field of electrical engineering and it is reasonable to expect that they will have a considerable effect not only in related areas but also on other electric equipment designed for nonmissile applications. When it is realized that at least half of the engineering effort which goes into a modern missile system involves the field of electrical and electronics engineering, the challenge to the electrical engineering profession and its impact on the future of the profession becomes most apparent.

History

ALTHOUGH CRUDE ROCKETS have been used for military purposes for many years, the significant highlights in the history of missilry and space flight prior to 1930 may be essentially measured by the efforts and endeavors of three individuals, Tsiolkovskii, a Russian; Goddard, an American; and Oberth, a German. Tsiolkovskii, about the turn of the century, was the first to recognize that the rocket engine possesses unique capabilities as a propulsion mechanism for traveling into space and in 1895 published the first serious scientific treatise dealing with space travel and related subjects. In 1903 he noted that it is possible for rocket vehicles to attain velocities in excess of the 25,000 miles per hour needed to escape the earth's gravitational attraction without imposing intolerable accelerations on a vehicle or its occupants and, additionally, that such vehicles could function efficiently and reliably in the vacuum environment of space. Analytical work on propulsion systems culminating in actual engineering design concepts for rocket vehicles was carried out by Oberth during the period immediately following World War I. Goddard, starting in 1919 with the publication of a study entitled "A Method of Reaching Extreme Altitudes," is probably best known for his pioneering work on the development of elementary but practical rocket designs and for the construction and actual field testing of rockets.

A large Goddard rocket being loaded into the launching tower in New Mexico.

In general, the era preceding World War II was characterized by very limited interest in rocketry on the part of the general public and most government officials. However, in Germany the government did provide active support for rocket experiments beginning about 1933. By the beginning of World War II considerable progress had been made, and by September 1944 the *V-2* was operational against London. This ballistic missile was the most sophisticated guided weapon in World War II.

During World War II, all of the belligerents used artillery rockets. Examples are the American bazooka, the barrage rockets used in the Pacific landings, and the HVAR launched from aircraft. The British employed rocket barrages in antiaircraft defense against German air raids made on London. The Soviets defended Stalingrad against the Germans with the *Katyusha* surface-to-surface rocket. Perhaps the largest of these artillery rockets was the American *Tiny Tim* designed to be launched from airplanes and carrying a warhead equivalent to that of a shell fired from a 12-inch naval rifle.

All of these rockets were unguided except for some control of the initial launching direction which was established by a launching tube or rail. However, they were very effective in delivering a great weight of explosives against an area type target and required very simple launching equipment.

The first guided missiles used in World War II were controlled bombs dropped from aircraft and guided onto the target by radio signals from the launching airplane. Difficulties were experienced from electronic countermeasures and from the requirement that the bombing plane fly a straight course during the control period. In order to remove this latter restriction, experiments were conducted, both in Germany and the United States, with a television camera mounted in the bomb. This approach presented numerous electronic and aerodynamic problems, particularly since a human element, the bombardier, formed a part of the closed-loop control system guiding the bomb. At the end of the war, the Germans had a number of very ambitious guided missile projects under development, including the *Wassenfall* antiaircraft guided rocket and the *A-9* intercontinental ballistic missile.

The first Government-sponsored effort in the United States on research and development in rocketry started in 1939 when the Guggenheim Aeronautical Laboratory of the California Institute of Technology began work on rockets for assisted take-off of aircraft. The first JATO flight was made in August 1941, and shortly thereafter these rockets were produced in large quantities.

During the closing phase of World War II, the Jet Propulsion Laboratory of the California Institute of

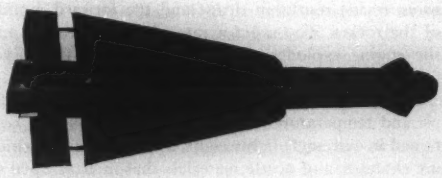
Technology, under the sponsorship of the Ordnance Department of the Army, undertook the development of a series of rockets to investigate the problems of long-range ballistic guided missiles. This included a 1,000-pound thrust solid-propellant rocket, the Private A, in late 1944, and a 1,500-pound thrust liquid-propellant rocket, the WAC Corporal, in late 1945. These developments, largely experimental in nature, culminated in a 20,000-pound thrust liquid-propellant test vehicle, the Corporal E, which was launched successfully in May 1947. This vehicle was the forerunner of the present day Corporal now in military operational use. Typical of other experimental missiles developed during this same period were the Navy's Viking and the Aerobee, a triservice sponsored development for upper atmosphere research.

Probably the most complex military missile system effort undertaken prior to the advent of the IRBM and ICBM developments was that of the Nike antiaircraft weapons system which is now in operational use protecting the major cities of the United States. Its development has passed through two phases, the Nike-Ajax and the Nike-Hercules. An advanced version of this system, the Nike-Zeus, is currently under development for use as an antimissile missile system. Nike is a multistage missile consisting of a solid-propellant booster stage and a liquid-propellent stage utilizing nitric acid and gasoline as fuels. The propellants can be stored in the missile so that firing can be accomplished on very short notice. The missile is guided to the target by a radio-command guidance system. It has proved to be remarkably effective in tests at the White Sands Missile Range and elsewhere.

In addition to the surface-to-air and surface-to-surface rockets developed about 1950, considerable work was carried out on air-to-air guided missiles. An example of this class is the Falcon missile, designed for aircraft launch, and fitted with a homing device to seek out the target.

The decision by the military in 1954 to undertake the development of IRBM and ICBM weapons systems undoubtedly marks the beginning of present-day large-scale effort in missilry and rocketry. Similarly, the de-

The Sergeant, a modern ballistic missile ready for launching.



Courtesy Hughes Aircraft Co.

The Falcon, an air-to-air guided missile, is fitted with a homing device to seek out its target.

Table I. Satellites and Space Probe Launchings

Date Launched	Popular Designation	Scientific Designation	Payload Weight (pounds)	Miles		Initial Period
				Initial Perigee	Initial Apogee	
Oct. 4, 1957	Sputnik I	1957 Alpha	184	142	588	96.2 minutes
Nov. 3, 1957	Sputnik II	1957 Beta	1,120	140	1,030	103.7 minutes
Jan. 31, 1958	Explorer I*	1958 Alpha	18	224	1,573	114.8 minutes
Mar. 17, 1958	Vanguard I*	1959 Beta	3.3	409	2,453	134.0 minutes
Mar. 26, 1958	Explorer III	1958 Gamma	18.6	118	1,740	115.9 minutes
May 15, 1958	Sputnik III*	1958 Delta	2,925	135	1,167	106.0 minutes
July 26, 1958	Explorer IV*	1958 Epsilon	25.8	163	1,380	110.3 minutes
Oct. 11, 1958	Pioneer I	—	39	—	72,000	—
Dec. 6, 1958	Pioneer III	—	13	—	63,600	—
Dec. 18, 1958	Score	1958 Zeta	150	124	908	102.0 minutes
Jan. 2, 1959	Mechta†	Artificial Planet No. 1	797	90.5×10^6	122×10^6	450 days
Feb. 17, 1959	Vanguard II	1959 Alpha	21.5	348	2,067	126.0 minutes
Feb. 28, 1959	Discoverer I¶	—	40	146	558	96.0 minutes
Mar. 4, 1959	Pioneer IV†	Artificial Planet No. 2	13.4	92×10^6	106×10^6	392 days

*In orbit, March 1959.
†In solar orbit, aphelion and perihelion shown.
¶Orbit uncertain.

cision of the United States to start development of the Vanguard scientific satellite program in 1955 under the sponsorship of the International Geophysical Year (IGY), marks the advent of the first concrete planning in this country to explore space. The rapid developments in missilry and space flight that have come about in the past year are still sufficiently well in mind to preclude any necessity for recounting them here. It is of interest to list the space flight achievements of recent months. Table I includes all known satellite and space vehicles launched by the United States and the USSR.

State of the Art

GENERALLY SPEAKING, the technology of missilry and space flight vehicles may be categorized into several broad areas which relate to the primary nature and functioning of the devices involved in the system. In the following sections, this approach has been used in describing the current state of the art, particularly as it relates to the electrical engineering profession.

PROPULSION

A ROCKET FIRING, to be successful, must be in many respects a restrained explosion. Relatively small quantities of very energetic chemical oxidizer and fuel must react within a pressure vessel to generate huge volumes of hot, high-pressure gases which are expelled rearward through a DeLaval nozzle at supersonic velocity. The rocket's reaction to the rearward expulsion of these gases (mass) results in thrust and the forward motion of the rocket. Too rapid a rate of gas generation and the engine explodes; too slow a rate and the rocket fails to take off.

Today, combustion gases at pressures of 300 to 1,000 psi and temperatures of 4,500 to 7,500 F must be contained in extremely lightweight, flyable structures which use chamber and nozzle materials that melt at 2,500 to 5000 F. In the case of a liquid-fuel rocket engine, designers have found that exposed members can be regeneratively cooled by circulating the liquid fuel or oxidizer over the heated surfaces before being injected into the combusion chamber. In the case of a solid-fuel rocket engine, the propellant is burned from the inside outward so that the unburned propellant insulates the chamber from the hot gases throughout the burning period.

With good engineering design, sufficient experience, and normal precautions, military rockets and guided missiles can satisfactorily perform their mission using these chemical propulsion systems. However, in order to perform the more advanced space missions of tomorrow, propulsion systems using nonchemical energy sources such as nuclear propulsion, ionic propulsion, and possibly photonic propulsion may be required. Even now, research is under way on some of the basic problems which must be solved before these more sophisticated types of propulsion systems can be practically employed. The solution of these problems is certainly to a large degree within the domain of the electrical engineer and it is to be expected that he will play an increasingly prominent role in the development and use of advanced propulsion systems for tomorrow's travel in space.

GUIDANCE AND CONTROL

THE ULTIMATE SUCCESS of a guided missile is measured by the accuracy with which it reaches its prescribed target. Thus, concurrently with the development of power plants and structures, it has been necessary to expend a very large effort on guidance and control and, fundamentally, the problem can be divided into these two areas. Control is essentially the problem of keeping the missile in stable flight and headed in a prescribed direction while guidance is the problem of mapping the missile's path in space, predicting its future path, and calculating suitable correction commands.

Control systems for guided missiles are similar in many respects to the autopilots developed for conventional aircraft in that the basic directional reference element is usually a gyroscope. Control may be effected through aerodynamic surfaces, or through control surfaces in the rocket jet, as in the *V-2* missile. Some of the larger ballistic missiles develop the necessary control force by swiveling the rocket motor so that the thrust vector moves with respect to the center of gravity of the missile. In the case of vehicles coasting in a vacuum, attitude control may be accomplished either by using small auxiliary jets or by moving masses within the vehicle.

In order to maintain the vehicle in stable flight, an amplifier with the proper transfer characteristic must be connected between the directional element and the control surface actuator. This amplifier forms a part of a closed-loop servo system with feedback being exercised through the dynamics of the vehicle and, by adjusting the transfer function of the amplifier, the necessary stability can usually be obtained. The situation is similar to that involving the airplane autopilot but is more complicated because of the wide range of time varying parameters which must be accommodated. For example, a missile may have to be controlled while flying in air wherein density varies from sea level to vacuum conditions while at the same time the speed may be rapidly increasing from subsonic to hypersonic, the mass of the vehicle may be decreasing to perhaps 20% of its original value, and a large shift may be occurring in the position of the center of gravity. All of these factors make autopilot design for missiles a science calling for considerable engineering ingenuity.

Guidance systems for missiles have ranged in complexity from the simple manually guided weapons of World War II up to the elaborate systems now being designed for space exploration vehicles. Manual guidance of a missile requires that the operator be able to see the paths of the missile and the target and have available a control system to permit flying the missile into the target. To do this successfully, he must obviously have acquired, through experience and training,

sufficient "feel" for the dynamics of the missile and its control system to permit exercising the proper control signals. Such systems can be surprisingly successful for relatively short range, slow flying devices. During World War II both sides developed aerial bombs which were manually guided into the target and the Germans developed manually guided antiaircraft missiles. Since that time, a number of battlefield short-range weapons have been developed for effective use against tanks and fortifications.

The guidance operator for these weapons usually has a small joy-stick control and an optical sight. His commands are sent to the missile either by radio or through wires. Because of its simplicity and freedom from interference, wire control has been favored for many of these devices. The wire is carried on two spools in the missile, unwinds freely in flight, and problems of wire breakage and short-circuits have apparently been successfully solved. Examples of present day manually controlled weapons are the U.S. Army Dart, the La-Crosse, the French *SS10*, and the Swiss Moskito.

The next step in guidance complexity is probably best represented by the *V-1* weapon of World War II. This device was essentially a small airplane controlled by an autopilot which gave commands to fly in a given direction at a fixed altitude until over the target following which the aircraft dived into the target. Since the weapon was primarily used against London and was not expected to hit precisely on a specified area, the accuracy could be, and was in fact, quite low. The performance was determined by the accuracy of the autopilot, knowledge of wind conditions, and the accuracy of the device for measuring range. Range was determined from a simple windmill mounted in the nose of the *V-1* which triggered the final dive after a pre-set number of revolutions.

It is quite clear that an autopilot plus rough distance measurement cannot be very accurate for a long flight at relatively low speeds within the atmosphere. In order to correct for meteorological conditions some of the *V-1* missiles carried a radio transmitter which sent a signal at the time of the dive command. By direction finding on this signal, it could be used as a "sighting shot" and appropriate corrections could be applied to succeeding shots. Even with this refinement, the *V-1* system was clearly a rather primitive guidance system.

The *V-2* rocket was a purely ballistic missile similar to an artillery shell. The conditions at thrust termination thus determined the impact point. Guidance was accomplished by an autopilot containing two gyroscopes as reference to determine the missile heading and a device for measuring velocity in order to command motor shut down. The missile was launched vertically and then pitched over in the direction of the target. One gyroscope maintained the correct azimuth heading, the other gyroscope was precessed over at a predetermined rate and thus the missile pitch angle was controlled to vary as this pre-set function of time. When the correct velocity had been reached, the motor was shut down and the missile flew a ballistic path to impact.

German V-2 ballistic missile in which guidance was accomplished by an autopilot containing two gyroscopes as reference to determine missile heading.

Velocity is a critical parameter for ballistic missile accuracy. Consider the case of a projectile launched at 45° to the horizon. For distances up to a few hundred miles the range is proportional to the square of the velocity and, therefore, velocity measurement must be as precise as possible. Several methods were tried in the *V-2* program and the two most interesting were the use of a precessing gyroscope to measure and integrate the acceleration, and the use of a radio Doppler system to measure line-of-sight velocity directly.

The gyroscopic accelerometer utilizes the principle that a gyroscope precesses at rate proportional to the applied torque. If this torque arises from an unbalanced mass in an acceleration field, then the rate of precession is proportional to the acceleration of the system. Therefore, the angle through which the gyroscope precesses is proportional to the integral of the acceleration with respect to time, or the change in velocity. This type of accelerometer can be made very accurate, but as used in the *V-2* it measured the axial acceleration of the missile, not the true acceleration along the path.

The radio Doppler system as used in the *V-2* was the forerunner of the DOVAP system now used as an instrumentation device for measuring missile velocity at the test-range firings. A radio signal is sent to the missile, received, doubled in frequency, and transmitted back to the ground. At the ground station, the signal received from the missile is compared in frequency with twice the original transmitted frequency. The difference frequency is an audio tone which can be measured very precisely; hence, the line-of-sight velocity can be very accurately determined. However, in order to use this system to calculate the missile impact point,

Official U.S. Air Force Photograph

The Atlas on its launching stand at Cape Canaveral, Fla.

it is necessary to know the missile position and the direction of the tangent to the flight path. If Doppler signals alone are used to determine motor shut down, the impact accuracy will deteriorate to the extent that the missile has deviated from its nominal trajectory near the shut-down point. The *V-2* missile guidance system was some improvement over the *V-1*, but it still was not accurate enough for present-day objectives. At the end of the war, the Germans were preparing to take the next step, namely, to use a stable platform in the missile.

The guidance systems of modern ballistic missiles and space vehicles fall into two broad categories: radio command systems and internal navigation systems. In each case, the basic problem is to "map" the path of the vehicle and then calculate the necessary steering commands to attain the desired objective.

A radio guidance system thus consists of a very precise radio direction-finding device on the ground which measures the direction of the signals arriving from the missile. In addition, it must measure the range to the missile and the vector velocity of the missile. With this information it is now possible to calculate, on the ground, the appropriate commands which must then be transmitted to the vehicle.

An internal navigation system must perform the same measurements and calculations as does the radio system but do it from within the missile. This can be done either by making observations on external objects, such as stars or objects on the surface of the earth, or it can be accomplished by carrying a "stable platform" in the missile. The stable platform is merely an object which is kept precisely oriented either in its initial position or in some other known position in inertial space. Three mutually perpendicular accelerometers mounted on this stable platform permit measuring the acceleration of the vehicle in inertial space and, by integration of the accelerometer outputs, the position of the vehicle relative to its launching position may be calculated.

At the present time, these "inertial" guidance systems are attracting a great deal of interest particularly for military applications. They require less equipment at the launching area and, once the missile is launched, no extraneous signals can cause interference with the guidance commands. However, it is evident that an inertially guided missile requires considerably more complex equipment within the missile than does the radio guided system.

Navigational systems using celestial bodies as directional references have not been used in ballistic missiles, however, vehicles which travel far out into space will probably need such systems if maneuvers are to be carried out. For example, a vehicle launched toward Mars may complete its thrust program in the vicinity of the Earth and then coast the remainder of the way. In this case, very precise control of the initial conditions of the coasting orbit is necessary and perhaps an Earth-based radio guidance system will be used. However, if the vehicle is accelerated for a large part of its travel by one of the low-thrust ionic propulsion devices now under consideration, a celestial navigation device would be almost essential. This is because the great distance from the Earth would make a radio guidance system inaccurate, while the very long flight time and very low acceleration would also make an inertial guidance system even more inaccurate.

Guidance systems may combine elements of the basic radio and inertial systems to advantage. Thus, a radio-inertial system, when properly designed, can take advantage of the fact that range is directly measured by the radio part and acceleration by the inertial part of the system. By properly combining the data from both systems, it becomes possible to obtain more accurate data than is possible with either one alone.

The problems associated with the development of improved and simplified guidance and control systems undoubtedly pose one of the greatest challenges facing the electronics engineer today. Not only must he develop systems which operate in the field with the degree of accuracy normally found only in a standards laboratory, but also he must design these systems to operate under extremely adverse environmental conditions.

ELECTROMECHANICAL DEVICES

MISSILES REQUIRE A VARIETY of electromechanical devices ranging from solenoid valves to gyroscopes. In considering the developments of the past 25 years, probably the most significant are those associated with in-

ertial guidance; namely, the small precision gyroscope and the precision accelerometer.

The breakthrough in gyroscopes came in 1940 when Dr. Stark Draper of MIT (Massachusetts Institute of Technology) first developed the floated gyro. The gyro wheel and its drive motor are sealed in a container which is floated in a liquid. The container is free to rotate about an axis at right angles to the spin axis of the wheel, thus constituting a system having a single degree of freedom. Because of the flotation, most of the loads are taken off the bearings and the device can be made to be remarkably free of the effects of vibration and acceleration. If the flotation liquid is chosen to have the proper viscosity, the gyro can then be used as an integrating device. The torque acting on the floated gyro is proportional to the angular velocity about the sensitive axis, and if the motion is restrained by the viscosity of the liquid, then the angular velocity of the gyro is also proportional to the torque. The gyro then turns through the same angle as the sensitive axis. The Draper gyroscope is used in many missile guidance systems, although other very precise gyros have also been built using more conventional schemes. Perhaps the most interesting of these is the air-bearing gyro which minimizes frictional effects by supporting the gyro on a thin film of air.

Precision gyros which are used in missiles are always associated with stable platforms and are used to keep the platform accurately oriented. By mounting the gyros on the platform no appreciable movement of the gyros with respect to their mounting frames is required and single degree of freedom gyros designed for small angular motions have proved quite satisfactory.

The other precision electromechanical element of an inertial guidance system is the accelerometer. These have been built using a variety of principles. The simplest kind is a moving mass type in which the movement is constrained by a spring. A constraining magnetic field induced by an electric current is often substituted for the spring and the strength of the current necessary to hold the mass in its original position is a measure of the acceleration. The precessing gyro used first by the Germans on the *V-2* is also a useful integrating accelerometer.

Generally speaking, it can be said that the gyros and accelerometers which are now available have laboratory performances of such sensitivities that it is difficult to measure their accuracy. Stability, linearity, and drift limitations of these devices under flight environment conditions are probably the determining factors controlling the guidance accuracy of most ballistic missile inertial guidance systems. There is a continuing search for improved methods and devices to provide for the precise measurement of linear acceleration and means of maintaining to a high degree, an inertially fixed, reference direction.

The problems of space navigation accentuate the difficulties of inertial guidance systems. Very long times of flight mean that drifts in the guidance components will impose serious limitations on the accuracies to which prescribed trajectories may be held. At the same time, the great distances traveled involve the establishment of trajectories which are extremely sensitive to the cutoff conditions existing at the time of injection. This is particularly true of the flight paths which involve orbits that are to be of the minimum energy type. Therefore, injection into the orbit requires a guidance system of the highest order of accuracy.

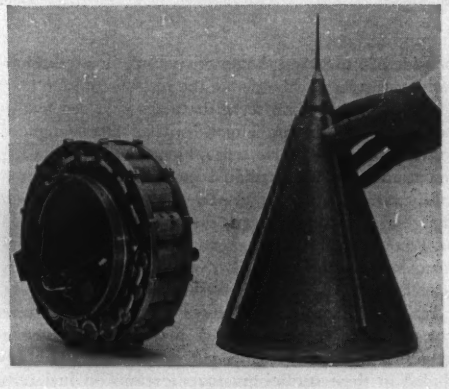
SECONDARY POWER SUPPLIES

ALL MISSILES require a source of electric power to operate the control and guidance equipment. To date, chemical batteries, solar cells, and both primary and secondary cells have been used. The criteria for selection are reliability, field usability, and energy output per pound of weight. Since, in missile applications, useful life is measured in seconds or minutes, the battery is also chosen to have a high discharge rate capability. Prefiring checks and warm-up of the equipment are usually carried out with a separate use of power in the test equipment.

The present trend in battery power sources is to use primary cells which are activated at the time of firing. A typical output figure for a zinc-silver cell, including the necessary activation mechanism and mounting appurtenances for missile application, is about 16 watt-hours per pound in packaged form.

Generation of electricity by a turbine driven by gas derived from a chemical energy source has been employed in some missiles. As an example, hydrogen peroxide, which can be decomposed by a catalyst to form steam to drive a turbine geared to an electric generator, has been used. Some missiles utilize compressed gas to pressurize the propulsion system and, in at least one case, this gas has also been used to drive a turbo-alternator for supplying power.

Space vehicles require power sources which operate for considerable periods of time. The first satellite vehicles, such as the Explorers, used mercury cells which



Instrumentation package of Pioneer IV.

Jupiter rocket with Pioneer-IV preparatory to launching on March 4, 1959. The 13.4-pound payload of this satellite is in orbit around the sun, having a period of 392 days.

provided 25 to 27 watt-hours per pound. One set of batteries was sufficient to operate the instrumentation load for 2 weeks. A second set of batteries operated a low-power transmitter for 2 months. The first Vanguard test sphere carried solar cells which are still operating the transmitter at a radiated power level of about 5 milliwatts. Sputnik III also carries solar cells which charge a secondary battery. The mercury cells utilized on Pioneer IV provided operation of the payload instrumentation for a period of approximately 82 hours after launch.

Serious studies are now under way to develop new types of reliable and compact power sources having long life and high outputs per pound of weight. Included in these studies are investigations on fuel cells and nuclear energy sources of various types. Each of these types appears to have certain inherent limitations in terms of volume, weight, or working media complications, which curtail their application in the field of missilry at the present time and in the foreseeable future.

Ideally speaking, a power source for missile and space vehicle applications would be one which has definite life, is not affected by its environment, has high output per unit volume and weight, and which derives its energy input from some radiation existing in space. The lack of such a device may prove to be the greatest limitation affecting long-term space experiments; for, without power, a satellite or space vehicle is merely a dead object in space. Obviously, a very definite challenge to the electrical engineering profession exists in this area.

COMPUTERS

COMPUTERS ENTER into missile programs in three areas: design, instrumentation, and guidance. Both analog and digital computers have been widely used, and indeed, the rapid development of computer technology has been greatly encouraged by the missile industry.

At the design stage, computers may be used, for example, to make trajectory analyses, to help solve the guidance problem, and to help design the control system. Analog computers are particularly useful for control problems and digital computers are useful in trajectory calculations. Experience indicates that both types play an important role in the field of missilry developments.

When a missile has entered the flight-test stage, computers are needed for flight data analysis. Telemetering data does not usually require many calculations but the reduction of trajectory data requires a great deal of calculation. Consider, for example, the problem of obtaining the best estimate of the actual flight path from a mixture of raw data coming from phototheodolites, radars, Doppler systems, etc. As the missile path evolves into that of an accurately guided device, the instrumentation system may be hard put to get trajectory data sufficiently accurate to permit evaluation of the guidance. In fact, some years ago, an error in the survey at the White Sands Missile Range was discovered by a missile guidance system.

In addition to the detailed trajectory data, it is also necessary to develop some trajectory data in real time as the flight progresses. This is primarily needed for range safety purposes and may be in the form of an impact prediction which shows where the missile would land if thrust were terminated at any given instant. Such an impact predictor is usually an analog computer operating on data from radars or theodolites.

Missile guidance systems require computers which operate in real time to solve the guidance equations. These are special-purpose analog or digital devices designed with the appropriate logic and terminations. Radio guided missiles have most of the computing done on the ground, and more or less conventional computer designs may be used. In the case of inertially guided missiles, however, the computations are done within the missile so that the computer must be designed within the size, weight, and power consumption limitations and the environmental conditions imposed by the missile. Solid-state and magnetic devices are fortunately now available for such applications, and are being widely used.

A very extensive computing problem which arises as a part of a missile system is that of the early warning network. Data is collected from radar stations around the boundaries of the United States and then analyzed by the SAGE system. The analysis must be in real time and mistakes cannot be made. In a certain sense, the entire network of stations and computers may be thought of as constituting one large computer.

A somewhat similar computation problem exists with space vehicles, since the tracking and observing stations are widely scattered around the world. Data and predictions have to be passed to these stations from a computer determining the orbital conditions, and much of the operation must be in real time. The Vanguard computing center in Washington, D.C., and the minitrack stations in South America constituted this sort of network for the IGY satellites. In the near future, the United States will be operating a much more extensive network. The Goldstone tracking station near Barstow, Calif., is typical of the stations which will be established. This station, and one in Puerto Rico, were used in tracking the Pioneer III and IV lunar probes. The computer utilized in these operations was located at the Jet Propulsion Laboratory in Pasadena.

INSTRUMENTATION

INSTRUMENTATION DEVELOPMENTS during the past 25 years have been a necessary adjunct to the basic research and development which underlie the whole missile and space program. These developments, almost without exception involve electronics, and it is safe to say that without the aid of the electronics engineer, today's guided missile industry would not exist.

Perhaps the most important factor has been the understanding of, and the ability to handle and analyze, very rapidly varying data. Consider, for example, the development of a rocket motor. One of the most significant problems is that of combustion stability. In order to observe merely the essential elements of the phenomenon, it is necessary to measure combustion chamber pressure transients occuring in times of a millisecond or less. The development of recording equipment having this capability represents only the beginning of the problem. Pressure gauges must be built with finite mechanical elements and must be connected to the combustion chamber by some sort of fluid transmission line. In order to obtain the relation between the actual chamber pressure fluctuations and the electrical output of the gauge, the engineer finds himself facing a problem which is directly analogous to the electrical engineering problem of a long transmission line with a mismatched load as a termination. The mathematical techniques for handling transient response of electric circuits have thus provided the instrument engineer with a much needed tool.

Telemetering, or measurement at a distance, is an old story to the electrical engineering profession. The basic principles of telemetering electrical quantities over wire circuits have been developed into the modern radiotelemetry system. Speeds of response have been raised into the kilocycles-per-second region. Equipment has been miniaturized and transistorized. Both digital and analog techniques have been employed.

The telemetry most widely used in the United States is a double FM system. The quantities to be measured are converted into a set of audio frequencies, each of which may vary over a frequency band 15% wide.

The antenna at the Goldstone Station, where Pioneer IV was tracked to approximately 407,000 miles before its signal was lost because of battery power expiration.

These audio tones are then transmitted to the ground over a frequency-modulated radio link and the tones are recorded. To obtain the data, the tones are separated by filters and the frequency of each is measured as a function of time by passing it through an appropriate frequency discriminator.

The basic FM-FM system was established as a standard for the guided-missile test ranges about 1949. It consisted of a set of 15 subcarrier tones ranging from center frequencies of 400 cycles to 70 kc. Each subcarrier is varied up to plus or minus 7½% by the quantity to be measured. Experience with this system has been very satisfactory. By subcommutating channels and even mixing low-frequency channels on the highest frequency channel to produce a triple FM system, it has been possible to make in excess of 100 measurements with a single radio-frequency transmitter. Of course, most of these measurements are of slowly varying quantities. Rapidly varying quantities, such as vibration measurements, require the assignment of one of the high-frequency subcarriers for each measurement.

Modern developments in telemetry lie in two directions. Equipments are being improved to provide greater reliability and accuracy with less weight and volume. Information theory is being used to develop more efficient systems. Space vehicle requirements particularly demand the most efficient communication system possible. The most significant recent development in this area is the microlock system used by the Jet Propulsion Laboratory on the Explorer satellites and the Pioneer lunar probes. Microlock uses a synchronous detection receiver which has an exceedingly narrow radio-frequency bandwidth and a correspondingly low-noise bandwidth. At the same time, by using narrow-band phase modulation, it is possible to transmit information over an arbitrary audio bandwith depending on the signal-to-noise ratio available. The system as built used four of the standard FM-FM subcarrier frequencies. The audio signals were passed through synchronous detectors acting as active, tracking filters, and then recorded with a bandwidth of the order of one cycle per second.

Experience with the microlock system has been very good and the system has performed close to its predicted values. It will undoubtedly be used as the basis for furthering interplanetary communication experiments in the near future. The most significant achievement of microlock is the fact that it is a working system that approaches the theoretical optimum. It is of interest to note that Pioneer IV was tracked by the Goldstone Station to a distance of approximately 407,000 miles before its signal was lost with the expiration of battery power. This represents the greatest distance over which an intelligible signal has been transmitted to date.

Space vehicles are presenting a new challenge to instrumentation engineers. Not only must the instruments operates successfully in the free fall, vacuum environment of space, but they must also withstand the difficult acceleration conditions imposed by the launching vehicle, and they must continue to operate, perhaps for years, without attention. A whole new class of problems will arise when instruments are designed for the surface exploration of the Moon or the planets. These instruments must be able to cope with the unknown and the unexpected, and have the capability of making optimum choices under these conditions. Obviously, this area too holds many interesting challenges to the electrical engineering profession.

In this short review it is not possible to cover any details of instrumentation achievements in the missile field beyond these few paragraphs. As a final observation, it is interesting to note that two of the most successful tools for high-speed recording have developed from commercial instruments designed for other applications. The modern recording oscillograph is an outgrowth of the instruments developed for seismic prospecting. The modern instrumentation tape recorder is a direct development from the high-quality audio recorders used in sound studios.

CONCLUSION

In the 14 years since the end of World War II guided missiles have been brought to the point of being in production and in the hands of the military forces in the field. Missiles which search out and find their target, even when the target is a modern supersonic aircraft, and missiles capable of traveling half way around the globe to deliver a nuclear warhead on a specified target, are no longer the fanciful dreams of a decade ago but now exist as actual working devices of

steel, aluminum, and electronic components. The space vehicles launched since Sputnik I merely represent part of the evolution of rocket technology. For the first time in the history of man, artificial planets are now whirling in orbit in the solar system. These space vehicles, while of momentary significance, are merely the second step forward after Sputnik I, and are only the elementary forerunners of developments of the future in the space age.

As this is being written, we are in the second year of the space age. Much has been accomplished, but surely this is only the barest introduction to the potential achievements of the next quarter century. These achievements will not be governed entirely by our technical capabilities but will, I believe, also be controlled to a significant extent by other factors. The complexity and cost of modern science and engineering requires that very large sums of money be made available to support experimental programs, particularly those involving the exploration of space. It is difficult to see how this support can come from sources other than the governments of the major powers of the world. Therefore, the rate of advancement in this area of technology may well depend upon the relationships existing in the future between the desired objectives of missiles and space programs, and the national and international attitudes and policies of the governments concerned.

To this end, I suggest that we, as members of a profession instrumental in advancing the technology of the future, should undertake more active interest in shaping these policies to insure that they provide for the use of the fruits of our efforts to the betterment of all mankind.

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The Role of Applied Mathematics in the Electrical Engineering Art

E. A. GUILLEMIN
FELLOW AIEE

THE EXTENT to which mathematics plays a significant role in engineering is synonymous with the extent to which engineering is identifiable with applied science. Engineering is a combination of the scientific and the practical. The extent to which either of these aspects predominates over the other cannot be defined, but depends entirely upon the nature of the problem dealt with and the ever-changing pattern of prevailing circumstances. Therefore, it is quite clear that the degree to which purely mathematical disciplines are coupled with or are essential to the activities of the engineer must be recognized as markedly varying with both time and geographical location. For example, 50 years ago in this country, the practical definitely outweighted the purely scientific aspects in engineering activity; 25 years ago, we might say that the two were reaching a competitive stage; today, it is fair to say that the emphasis upon science in engineering predominates so strikingly that a member of our profession whose background is not primarily scientific to a degree of substantial depth cannot identify himself with that segment of professional activity that dominates and, hence, characterizes its essential meaning or definition.

This statement does not imply that in present-day engineering problems the social and economic aspects as well as matters of practical expediency do not continue to exert their due weight upon significant decisions, but rather that the purely scientific aspects which dominate the surge of progress and sound the death knell of obsolescence are the compelling influence that molds our attitudes and guides our moves in the complex game of professional activity in this modern age.

It is true that such influences have always been present. The character of engineering has never been stagnant. But the pace at which it is changing today compared with the pace that prevailed 25 years ago is staggering to those of us who have witnessed both. As a sample of this sort of thing, compare the fact that assimilation of "innovations" involving the introduction of complex notation by Steinmetz and Kennelly was still engaging the electrical engineering profession at that

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time, with the 10-year period (centered in World War II) during which the far more subtle theories of random processes expounded by Norbert Weiner were so thoroughly incorporated into the working kit of the communications engineers that anyone not conversant with at least the essential aspects of these high-level mathematical concepts today can count himself among the obsolete fixtures that adorn the sidelines of this branch of the profession.

NUCLEAR DEVELOPMENTS

FAR MORE COMPELLING than this situation, however, is the fast-moving picture that accompanies the purely scientific developments in atomic and nuclear physics. These threaten, within the short space of decades, to alter completely our present conception of the so-called heavy-power or heavy-machinery industry. Here atomic power will outstrip even itself. Atomic power plants—the newest of the new—are conceptually obsolete even before they get well into the operating stage, for steam turbines and rotating machine generators will become museum pieces along with the rotary converter of a generation ago as soon as scientific research in fusion and plasma devices raises the capacity for direct conversion of atomic energy into electrical form to an adequate level—an achievement which no longer can be regarded as in the dim distant future, but one that may become a reality any day.

Molecular engineering—a term which has had a life history of only a few years—deals primarily with the synthetic creation of new materials having controllable properties surpassing those which are competitively supplied by nature. The doors which this activity may unlock for us in the near future are hard even to conjure up in our imagination, but one thing is certain and that is that "old man obsolescence" will here too be active and hard to outstrip.

These are but a few of the more phenomenal changes that have come about in recent years. If I may be allowed another comparison, let me say that before World War II, I felt quite secure in thinking that I was well informed and well grounded in all essential aspects of electrical communications. I wouldn't dare make that statement today, for since the war so many completely new disciplines have come into being (information theory, statistical communication theory, data processing and analysis, the logic of switching circuits and computer theory, just to mention a few) that it is no longer possible for one individual to be knowledgeable in all of them if he wishes also to maintain an active and creative position in one. And communications is but one of the several branches of electrical engineering that have mushroomed within this period.

IMPORTANCE OF MATHEMATICS

CERTAINLY the character of engineering has changed within the last 25 years, and particularly in regard to the importance that purely mathematical techniques and disciplines play in what we might call the everyday life of the electrical engineer. This is not true, of course, for all electrical engineers, for engineering by its very nature is far too diversified to permit such an all-inclusive statement, but it is true for a segment of our profession sufficiently large that none of us can any longer ignore this fact or the impact that its consequences will have upon all of us and particularly upon those of us who are primarily concerned with the training of young men for the engineering profession.

In the early development of the electrical art, it was primarily in the field of electrical communications that more advanced mathematical methods were needed. It was here that our modern concept of circuit theory or linear system theory had its origin. Problems in acoustics and in the electric transmission and reproduction of signals and speech were the motivation for fundamental contributions to linear system theory made by Lord Rayleigh, Oliver Heaviside, and George Campbell. Within the last 35 years, it was the same motivation that initiated and stimulated the problem of electric network synthesis, the solution to which led us in turn to discover that the purely mathematical theory of functions of a complex variable and potential theory contained the almost ready-made answers to a host of network problems and properties, and gave us a maturity of outlook upon linear system and signal theory that is at once the basis and the *modus operandi* in a glamorous new application of these methods known as operations research.

EMPHASIS ON POWER

CURIOUSLY ENOUGH, 25 years ago the communications sciences were regarded in the engineering colleges as the small and relatively unimportant adjunct to an electrical engineering curriculum dominated by large circuit breakers and heavy rotating machinery. When those of us interested in the more scientific aspects of our profession asked that room in the curriculum be made for advanced mathematics and physics by reducing the emphasis upon conventional electrical engineering practice, we were politely reminded that more money was being made in the electric power field and that while a deeper understanding of physics and mathematics might be the correct educational diet for a few impractical souls who mistakenly or dreamily were interested in unconventional things, such proposed changes could not be regarded as proper for the large majority of our students.

It took a war to change that attitude. For example, the war experiences in development laboratories such as the Radiation Laboratory at the Massachusetts Institute of Technology, made it abundantly clear to engineering educators that the conventional curriculum did not provide our graduates with an ability to deal with unconventional problems while the scientific type of curriculum to which physicists had long been accustomed did provide the flexibility of thought and the

fundamental tools with which to tackle and solve the problems in radar development. The work performed at the Radiation Laboratory was almost 100% engineering,

"...Yet R. L. was staffed largely with physicists, plus an admixture of other scientists (ninety-nine mathematicians, some biologists, chemists, geologists, and astronomers, a botanist, a physiologist, a a zoologist) who never had any engineering training . . . There were almost 500 physicists, mostly nuclear physicists. Almost every member of the Steering Committee and almost every second-rank leader was a physicist.

"At one time engineering scuttlebutt was that all this was a great mistake resulting either from a misunderstanding of British practice or from the fact that so many radio engineers were tied up in radio work. In fact, the decision to hire a lot of physicists in the nuclear field, which embraces cyclotron work and electronic measuring, was taken deliberately by NDRC. Other physicists and other types of physical and natural scientists were hired on the theory that the fundamental nature of all scientific thinking and training is one, and that such men could rapidly be fitted into the high-level developmental work that R. L. was to undertake. Of course the scientists had to be taught something about engineering work—which was easier to manage than it would have been to raise sufficiently the theoretical level of a like number of engineers.

"Many of the scientists' achievements in R. L. were due not to the special lore of either engineering or physics but to the habit of mind that is called scientific. The broadly trained scientist is accustomed to making careful observations of natural phenomena and to seeking new truths on the basis of these observations. Longhairs love to question standard practice, whether engineering or any other . . . Sometimes indifference to rule books, a willingness to gamble, led to a flop. But often it led to success for which other approaches could not or did not suffice."[1]

CHANGE IN ATTITUDE

TODAY the pendulum has swung a long way in the other direction. So-called "electrical science" curricula are springing up in almost every forward-looking engineering school. In fact, an engineering college just isn't in the latest fashion today unless such terms as "solid state," "molecular engineering," "probabilistic this or that" appear in the catalog. In sharp contrast to the attitudes that held sway among electrical engineering educators only 20 short years ago, this is an age in which the emphasis is upon science and the scientific method. Whether this about face has been due partly to popular hullabaloo that glamorizes science by dazzling the public mind with science-fiction-like stories in newsprint, movies, and television programs, or to sober reflection, or to obsolescence on the part of an aging faculty, doesn't really matter. The important point is that a changed attitude has been achieved and that we are engaged in a remodeling job with regard to our engineering educational programs that is destined far better to provide our young engineers with the tools that they will need to solve the diverse and almost unpredictable problems that are sure to present themselves within the next decade and in those following it.

In this "face-lifting" enterprise, applied mathematics is playing a prominent part along with basic physics which, in large measure, is hardly distinguishable from it. Whereas 25 years ago the inclusion of introductory material on differential equations in the required engineering curriculum was regarded as an indulgence in scientific pretext, it is not uncommon today to extend our mathematical requirements to include as a regular diet advanced algebra, vector and tensor analysis, complex function theory, probability and statistics, and Fourier and Laplace transform theory, with such things as formal logic, set theory, Hilbert space theory, calculus of variations, integral equations, and boundary-value problems in the category of likely electives according to the student's field of specialization.

Engineering across the board (and electrical engineering, in particular) has undergone tremendous changes with regard to utilization of abstract theoretical principles. Although a good share of the investment is still in the heavy power area, a very sizable slice of it is distributed among the exploitation of techniques and devices in the so-called "weak-current" (Schwachstrom) field, and the ratio of the latter to the former is growing year by year. Prediction is that the theories born of financially weak ancestors will conquer and banish forever the kind of heavy machinery which the power industry has for so long boasted as being the warp and the woof of electrical engineering.

Throughout these past 25 years, applied mathematics and basic science have become ever more prominently the electrical engineer's most essential tools; and there is every likelihood that this trend will continue for some time to come. Both professionally and in our educational activities this is perhaps the most prominent feature characterizing the modern attitude in electrical engineering.

REFERENCE

1. Longhairs and Short Waves. *Fortune*, New York, N. Y., vol. 32, no. 5, Nov. 1945, p. 169.

The Transformation of Electronic Communications

E. W. ENGSTROM
FELLOW AIEE

A DIFFICULTY FACING all of us who summarize various portions of technological history in the past quarter century for this anniversary issue of *Electrical Engineering* is the utter distortion of the once comfortable relationship between time and technical progress. In a previous generation, the historian assigned himself a century or more of engineering development in order to describe an appreciable advance. Today, by contrast, a decade is likely to give him as much as he can handle. In going back as far as 25 years, he finds himself in an age which, if not actually dark, is at best only dimly lighted by present standards.

A case in point, to be developed in the following pages, is the transformation of electronic communications—radio and television—during the past quarter century.

In 1934, there seemed ample justification for regarding our achievements in this field with some satisfaction. Broadcast radio, comprising hundreds of network and independent stations, reached into most of the homes of the nation. Television, while still in the laboratory, had achieved in nearly all essentials the basic form of today's system and was about to enter upon a career of field tests and engineering improvements. International radio communications, already proved in years of service, effectively carried a substantial volume of commercial traffic around the world. Military communications, employing techniques almost identical to those used in various commercial services, were adequate both to the times and to the strategic concepts of the period between the two World Wars.

As a measure of the progress during the ensuing 25 years, consider the radio-frequency spectrum employed then and now.

Today, the useful spectrum extends up through the very-high frequencies (vhf—from 30 to 300 mc (megacycles) per second), the ultrahigh frequencies (uhf—from 300 to 3,000 mc), and the superhigh frequencies (shf—from 3,000 to 30,000 mc). In addition, we are exploring the use of yet higher frequencies, employing millimeter wavelengths, for certain specialized services, particularly related to radar. Within these frequency ranges above 30 mc lie *all* of our television and FM radio broadcast services, *all* of our microwave communications, and *all* of our radar systems.

Twenty-five years ago, all standard broadcasting employed frequencies between 500 and 1,600 kc. In commercial systems, a very few pioneering chains, such as the radio-telephone link among the islands of the Hawaiian group, penetrated a short distance into the vhf range with frequencies as high as 60 mc. No apparatus existed outside of the laboratory for either commercial or military operations at higher frequencies. In other words, our radio communications of 1934 were restricted almost entirely to frequencies representing only 0.1% of the useful spectrum of 1959.

THE TREND TO HIGHER FREQUENCIES

THERE WAS CLEAR RECOGNITION at that time that the higher frequencies afforded the elbow room vitally needed for the further expansion of radio services and the introduction of television as a new mass communications medium. It was this recognition that inspired the major trends of technological development up to and through World War II. During this period of 10 years or more, the emphasis in electronics research and development was upon the creation of tubes and circuitry for vhf and uhf operations, and upon application of these advances to new or improved radio and television service.

A logical point of attack was the building-block of all electronic equipment of the time—the electron tube itself. Since there is a direct relationship between wavelength, on the one hand, and the dimensions of the tube and the spacing of its elements on the other, the major trend was toward reducing both size and spacing without sacrifice of performance. This was not as simple as it may sound. The limits of conventional tube performance were fixed by such considerations as the inductance of the leads, transit time of electrons between electrodes, and problems of heat dissipation in small structures. To a large extent, the barriers were to be overcome with new principles and unorthodox construction, resulting from intensive research and engineering.

An outstanding advance in the early 1930's was the "acorn" receiving tube, so called because of its resemblance in size and shape to an acorn. Introduced commercially in 1935, the acorn tube broke new ground in at least two significant respects. These were the very close spacing of the elements within the tube, and the special design of leads to reduce inductance effects. The result was an extremely small tube of the conventional grid type, oscillating at frequencies never before achieved by conventional types. Operating at about 500 mc, in the uhf range, the acorn tube initiated an era of receiving-tube development leading to

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compact and portable equipment with low power requirements. It was followed later in the decade by notable further advances, such as the planar and disc-seal tubes used extensively in the microwave communications and radar systems of World War II.

By the later 1930's, the application of new principles had led to significant advances in amplifier and transmitter tubes for the higher frequency ranges. New names, new configurations, and new levels of performance followed one another in bewildering succession as the decade closed. The inductive output tube, providing useful wide-band amplification up to 500 mc, was put to use in television relay service. The klystron, appearing in 1939, became the standard oscillator for frequency changing in superheterodyne microwave radar receivers, with performance extending up through the entire shf range. The magnetron, carried through many stages of development that bridged the entire decade, emerged as a thoroughly effective transmitting tube at microwave frequencies. With the development of the resonant cavity magnetron in England at the outset of World War II, the means were at hand to supply a multitude of radar systems with large amounts of pulsed power at ultrahigh and eventually at superhigh frequencies.

These were highlights of a broad advance in tube technology during the decade after 1934. The products of this advance were new basic tools for all forms of electronic communications—a family of ingenious devices for transmitting, amplifying, and receiving over a vastly greater range of useful frequencies. The systems employing these new frequencies were developed with equal swiftness, aided by impressive scientific and engineering accomplishments in specific fields.

RADIO AND TELEVISION IN THE PRE-WAR ERA

IN BROADCASTING, both FM radio and television were largely perfected in the technical sense by the time of the outbreak of World War II. Shelved by the overwhelming demand for military systems through the war, they awaited the return of peace to exert their full impact upon the field of mass communication.

The use of wide-band FM in radio broadcasting appeared to offer certain important advantages, such as the reduction of high-frequency hissing sounds developed in the receiver. In order to benefit from these characteristics of FM, however, it was necessary to employ a far wider band of frequencies than those used for standard AM broadcasting. In fact, the bandwidth of 150 kc proposed for the FM system was too great to be accommodated in the 550- to 1,600-kc range of AM service. Sufficient room was becoming available, however, in the expanding vhf portion of the spectrum. Moreover, the use of the higher frequencies with their shorter wavelengths offered the added advantage of relative freedom from all forms of natural static.

With the advent of ever higher frequency apparatus through the 1930's, new facilities became available for tests and studies of wideband FM broadcasting techniques. By 1939, the first high-power vhf–FM transmitting station had been established. Within a year, a dozen other stations were in operation, laying the base for rapid extension of FM commercial service in the postwar era.

In television, it was a notable era. From 1934 to 1939, the system progressed from experiment to pioneer public service in both the United States and England. In this country, the development was carried forward principally in a broad and intensive systems program. The objective of this program was not only to achieve maximum technical effectiveness, but also to prove the practicability of television as a broadcast service. Its various aspects ranged from laboratory activity to the construction of studios, the development of transmitting facilities and relay links, the production of hundreds of home receivers, and development of programming techniques.

The details of television progress through the 1930's are beyond the scope of a relatively brief review. Among the highlights, however, were several outstanding research and engineering achievements. The "eye" of the television system—the iconoscope—was the subject of exhaustive research aimed at improving its sensitivity. These studies led to successive improvements and, by 1939, to the invention of the orthicon, a new type of pickup tube of far greater efficiency, capable of operation at light levels too low for the iconoscope. The orthicon saw only limited service before giving way to the more effective image orthicon, a wartime development that remains today the standard broadcast television camera tube.

Intensive studies also were devoted to luminescent materials, with the objective of developing phosphors of maximum brightness for the television picture tube. More than 6,000 different materials were synthesized and tested in the course of this research effort, resulting not only in greatly improved television viewing

Courtesy RCA

The "acorn" tube, at right, introduced in 1935, was the first commercially available receiving tube operating at ultrahigh frequencies. With it is miniature tube developed subsequently for wartime use in high-frequency equipment.

screens but also in a major contribution to development of the fluorescent lamp.

Perhaps the most striking aspect of the television effort through the 1930's was, however, the creation at an early stage of a complete working system in which new theories, materials, and equipment could be tested under field conditions. Developed during 1935-36, this system comprised studios and transmitting facilities in New York, and a relay link to the Philadelphia–Camden area. As specific improvements or innovations emerged from the laboratories and engineering organizations, they were placed in this extensive test bed for evaluation. The result was a rapid advance for the system as a whole, leading to the introduction of television as a public service at the New York World's Fair in April 1939.

Two years were still to elapse before the Federal Communications Commission (FCC) authorized the standards for commercial television broadcasting. The groundwork for this final step was laid, however, during the late 1930's by industry-wide studies and tests of the systems and components basic to standards of television transmission. From these studies emerged recommendations which were submitted to the FCC, whose approval was received in 1941—just in time to encounter World War II and the diversion of the Nation's electronic resources to the war effort.

RADAR MAKES ITS APPEARANCE

IN THE LIGHT of wartime needs, perhaps the most significant advances of the pre-war era in electronic communications related to fields other than broadcasting. Experiments in the early 1930's relating to centimeter wavelengths led rapidly to the development of apparatus capable of tracking objects at a distance by reflection of the extremely short waves from the object back to the transmitter. In 1934, for example, a microwave system demonstrated this phenomenon in tests at Atlantic Highlands, N.J., by following the courses of trucks, boats, and other moving objects.

Courtesy National Broadcasting Co.

Experimental broadcasting from studios in New York comprised an important part of television development in the 1930's. Cameras employing early iconoscope tubes are prominent in this 1937 scene.

Official photograph, U. S. Navy

Experimental radar installation aboard the USS Leary was tested successfully in 1937. This yagi-type antenna tracked ships and planes by movement of the gun to which it was attached.

From such beginnings, radar made its appearance as a new and potentially decisive military technique. By 1937, the means had been developed for pulsing the signals in order to measure the distance of detected objects, and for displaying the reflections on a cathode-ray tube. In 1938, radar equipment was installed for the first time on a United States warship, and similar equipment had been employed successfully to detect aircraft at a distance of 50 miles. Equally intensive development was, of course, being carried forward in other countries at the same time—notably in England. By the outbreak of World War II, British scientists and engineers had developed an early warning radar system for air defense, and further contributions from British laboratories soon led to development and widespread application of the resonant-cavity magnetron in virtually all Allied wartime radar systems.

The swift growth of commercial aviation during the 1930's provided yet another important field of application for the new vhf and uhf techniques of electronics. In addition to improved air–ground communications, these provided the basis for new air safety and navigation methods. Application of radar techniques, for example, resulted in the radar altimeter, capable of measuring actual height above ground almost instantaneously and with extreme accuracy. In air navigation, an outstanding development was the omnidirectional range, growing out of work which commenced in the early part of the decade. Its appearance in 1939 provided commercial aviation with an ingenious vhf radio beacon system capable of giving the pilot his exact bearing at all times regardless of weather.

WARTIME EXPANSION

THESE AND MANY OTHER ADVANCES in the pre-war decade laid the foundation for a multitude of striking wartime innovations in all forms of electronic communications. Adapted in constantly improved form to a variety of military requirements, radar, FM, microwave radio, and television contributed substantially to victory. At the same time, their further evolution and widespread application resulted in a major transformation of the communications art in the postwar world.

It should be recognized, however, that the phenomenal progress in electronics during World War II was based directly upon the scientific and engineering achievements of the pre-war years. In the rush for technological supremacy on a large scale, there was little time to explore applications of new basic knowledge when so much could be done in the way of improving and applying principles of proved value. Thus, the communications hardware of World War II represented primarily a major engineering advance, with benefits that would be translated immediately after the war into large-scale and effective commercial broadcasting, microwave, and radar systems.

These postwar innovations derived particular advantage from the substantial improvement of performance and reliability in virtually all electronic components and equipment during the war. The postwar era thus began with increasingly effective tubes for pulse and continuous-wave operation at ever-higher frequencies; more efficient phosphors for radar display tubes; new multiplex relaying systems and techniques; more sensitive pickup tubes and light-weight assemblies for television; effective airborne communications and navigation equipment, and compact and rugged circuitry of all types.

Photograph M. J. Ackerman

Typical of important wartime communications developments was the "Walkie-Talkie" two-way field radio.

Beyond these engineering advances, the most profound effects of World War II upon communications lay in the expansion of the radio-electronics industry and the tremendous growth of research and development under Government sponsorship. During the years from 1941 through 1945, the industry produced some $7.5 billion worth of military radar and communications equipment, employing a force of 550,000 workers in nearly 1,600 plants throughout the country. At the same time, great amounts of money were being poured by the Government into industrial, university, and governmental laboratories. The result was a wide production base and a vastly expanded scientific and engineering establishment.

Moreover, the requirement of specialized equipment and systems for military use spurred a redevelopment of major technological importance. This was the extension of electronic techniques on a large scale far beyond the communications and entertainment functions with which electronics had been so largely concerned in the decades before the war. During the war years and the postwar era, increasing emphasis was placed upon the development of electronic methods and apparatus for an ever-broader range of computing, data-handling, control, and automation functions, with profound effects upon many aspects of industry, commerce, and defense.

In the field of communications, the wartime expansion of production facilities enabled the electronics industry to meet the great pent-up demand for consumer products and industrial equipment which became immediately evident with the return of peace in 1945. Historically, the most striking example is the postwar career of television.

TELEVISION: FROM BLACK-AND-WHITE TO COLOR

HAVING MADE ITS DEBUT as a commercial service just in time to vanish for the duration, broadcast television had scored certain important technical gains as a result of wartime experience. Outstanding examples were the highly sensitive image orthicon camera tube, and improved transmitting equipment covering all of the 12 channels allocated for commercial television service. With these gains added to the system developed so painstakingly through the pre-war decade, television was prepared for phenomenal expansion. In the postwar environment, this potential was matched by consumer demand.

The results were explosive. The first postwar commercial television receiver was produced in 1946. By mid-1947, some 60 companies were manufacturing or developing receivers, and new television stations were sprouting across the landscape. Within 5 years—by the end of 1950—more than 12 million home television receivers had been produced and sold. During the same period, broadcasting facilities blossomed into a total of 107 stations serving viewers from coast to coast with either local programs or network fare carried by coaxial cable or microwave relay.

Courtesy RCA

All-electronic color television, represented here in laboratory tests of a three-tube image orthicon color camera, was an outstanding development of the postwar growth of mass communications.

The growth of the system was so rapid, in fact, that the FCC called a halt to new station construction in 1948 pending a review of frequency allocations. With only 12 channels available for broadcasting in the vhf spectrum, extensive studies were required to work out an allocation plan that could avoid congestion in many local service areas.

The search for methods to avoid such congestion involved technical as well as regulatory measures. The principal technical steps were the exploitation of unused channels in the uhf range, and the development of more precise frequency-control techniques for vhf stations. On the basis of previous engineering and signal propagation studies, an effective uhf system was developed during 1948 and 1949 and field-tested through 1950 from an experimental station at Bridgeport, Conn. During the same period, major technical advances were made in reducing co-channel interference in areas lying within range of two stations employing the same channel.

By 1952, station construction was renewed with FCC approval, and a new allocation plan was announced. This made room not only for some 500 additional stations in the vhf band, but approximately 1,500 stations in the uhf channels as well. Subsequent expansion of television service to the present has been accommodated largely in the vhf range, uhf up to the present having served only a lesser part.

During the 1930's, the prospect of adding color to the picture on the receiver had fired the imaginations of those who foresaw the ultimate extension of television itself into a nation-wide broadcast service. Some experimentation with color techniques had taken place in the pre-war era, but the development of an effective all-electronic color system awaited a series of further technical advances.

Two types of color system were, in fact, developed in the decade following the war. The first to make its appearance was the field sequential system. This employed an arrangement of mechanical color filters passing at high speed and in synchronism before the eye of the camera and before the eye of the observer at his white-emitting television screen to create the illusion of full-color images. The technique resulted in color pictures of good quality, but it possessed one particularly grave handicap. This was its incompatibility with the rapidly growing black-and-white television broadcasting service. To achieve good color within the frequency limits authorized for broadcasting, special broadcasting standards were required for transmission. The millions of black-and-white receivers in the home could not be synchronized with the transmission without service modifications at cost to the consumer. In spite of this drawback, the FCC in 1950 was sufficiently impressed with the quality and advanced status of the system to authorize its use in commercial broadcasting. As matters turned out, however, the system virtually disappeared from the broadcasting scene within a few months when the National Production Authority banned mass production of commercial color television equipment to conserve critical materials during the Korean crisis.

In the meantime, advances were being achieved with an all-electronic color television system that would be entirely compatible with the extensive black-and-white commercial service. Compatibility in this sense means the ability of monochrome receivers to pick up color programs in black-and-white, and of color receivers to pick up monochrome programs, with no special added equipment required in either case. This was essential to the smooth introduction of color television service into the existing pattern of television broadcasting.

Between 1946 and 1950, major technical advances had been achieved, resulting in transmission techniques that enabled a composite signal including all color information to be accommodated within the 6-mc bandwidth of a standard black-and-white channel. The final basic step was the development in early 1950 of the first effective tricolor kinescope—a single tube capable of receiving and displaying television images in full color. This outstanding achievement completed the technical foundation upon which an all-electronic compatible color system could be erected. During the next 3 years, continued engineering led to the development of larger and better color picture tubes based on the original type, and to simplification of receiver circuitry. Coincidentally, an industry committee agreed upon standards for recommendation to the FCC, based upon the all-electronic system. In December 1953, the new color standards won FCC approval, opening a new era of color television in commercial broadcast service.

Together with the development of the color broad-

casting system came a technical advance of considerable importance not only for television network service but for many aspects of communication. This was the technique of recording television pictures and sound on magnetic tape for storage and playback, in either color or black-and-white. Applied in network service by 1957, tape-recording techniques permitted the adjustment of network programming to the time zones across the country. A further significant development, still in the laboratory stage, was a home television tape player, capable of reproducing program material from tape through a standard television receiver. This development offers today the prospect of an important new industry based upon the television equivalent of the phonograph, presenting recorded sight as well as sound for widespread use in the home, in education, and in industry.

WORKHORSE TELEVISION

THE PHENOMENAL GROWTH of television broadcasting tends to obscure the fact that many of the early pioneers conceived of television more as a tool for the extension of human sight than as a system of mass communication. Economically, however, it was only the prospect of a mass market for television receivers and a mass audience for programming that could have justified the great investment of time, talent, and money needed to carry television to the practical operating stage. In the process, the techniques and equipment were developed which were essential to a practical "workhorse" television system for nonbroadcast use.

To a large extent, military television applications in World War II laid the basis for postwar progress in closed-circuit equipment for industrial, educational, scientific, and military use. However, widespread industrial and other nonentertainment television functions awaited the development of more compact, economical, and uncomplicated equipment. The breakthrough came in 1949 with the development of the vidicon, a new type of pickup tube only one inch in diameter and six inches long, with high sensitivity and resolution. Around this simple tube was developed a complete closed-circuit chain comprising a light-weight camera and portable control and monitor equipment.

The advent of the vidicon-camera-chain opened up an almost infinite number of possibilities for television in utilitarian functions. Coupled with a microscope, it became a new tool for medical research. Installed in the classroom, it became a new teaching medium. Ruggedized and packed into its most compact form, it became a portable field unit for military reconnaissance and news gathering. Packaged in special containers to resist heat and shock, it became a remote-control eye for watching a variety of industrial processes too confined or hazardous for direct observation. Ultimately, as a color medium employing three vidicon tubes and more elaborate circuitry, it became a closed-circuit color system for particular application in the medical field. By 1956, the flexibility of closed-circuit systems was further increased by the development of a scaled-down vidicon tube only half an inch in diameter and slightly more than 3 inches long.

While communications advances in the postwar decades were overshadowed by the dramatic growth of television, the impetus given to all areas of research and development during the war led to continued progress in many other directions. Microwave techniques were steadily improved and put to widespread use in industry and public services as a means of communicating both information and signals for the remote control of machinery. The traveling-wave tube, the principles of which had been developed just prior to the war, was introduced in improved form as a practical low-noise amplifier for microwave relay systems and for radar. In acoustics, improved microphones and loudspeakers led to increasing fidelity in radio broadcasting and listening. An advance of major significance, both artistically and commercially, is the recent advent of stereophonic-sound-reproduction techniques in both recording and broadcasting. Advances in communication theory and propagation studies brought steady improvement in long-distance point-to-point radio communications. In this area, a most important development was the advent of practical communications over increasing distances at very-high and ultrahigh frequencies, employing scatter propagation techniques. This technique carried vhf and uhf signals well beyond the horizon on a reliable basis for the first time by the use of powerful transmitters

Courtesy RCA

Advent of the vidicon pickup tube led to development of compact television systems for many nonentertainment uses, such as this application in a system for high-speed counting of blood cells and other small particles.

whose signals were scattered from the tropospheric and ionospheric layers above the earth and picked up at a distance by highly sensitive receivers.

THE REVOLUTION IN MATERIALS

THE LATTER 1940's were characterized by a healthy advance in all fields of electronic communications. In retrospect, however, it is clear that the time was ripe for the application of new scientific principles in order to continue and to accelerate the advance.

After several decades of research on free electrons inside vacuum tubes, attention was being turned increasingly in the postwar era toward the utilization of electrons moving within solids, or even localized within a given atom in a solid. A store of useful knowledge relating to solid-state electronics had been compiled through pre-war fundamental research at a number of universities in this country and abroad. In addition, some contributions had been made by industry through research on such phenomena as luminescence and electron emission. Applications of this knowledge had affected certain components in electronic systems, but had not altered primary dependence upon the electron tube as the basic circuit element.

A revolutionary change in this pattern came from industry in July 1948, with the announcement of the discovery of the transistor, a solid-state device in which the production and movement of free electrons could be controlled precisely by application of an extremely small voltage. With the advent of the transistor, it became possible for the first time to achieve, with extreme economy of power in a small solid-state device, the amplifying, oscillating, and detecting functions achieved previously only with the electron tube.

This development posted a new direction sign for the electronics industry. The ability of a small input to control a large output is the basis of all electronic systems. The electron tube was the first major advance along these lines. The transistor became the second. Following this discovery, intensified research and engineering development at many electronics research laboratories led to improvement and extensive application of the transistor. In a remarkably short time, complex technical problems were overcome, leading to a variety of transistor devices for many circuit functions and to effective methods of large-scale production. One index of these accomplishments is the swift growth of the transistor market: in 1954, sales totaled less than $5 million; in 1957, this had risen to more than $63 million, with estimates of a $150 million total by 1960.

In the general advance of electronic technology since 1950, the transistor ranks as the star of a large and illustrious cast, rather than as a solo performer. Research has led to many other materials and solid-state devices of direct use in communications and other electronic systems. The resulting trend is toward equipment of decreased size, low power consumption, and increased functional complexity.

The products of solid-state research include new methods of controlling electron action by the application of extremely small voltages or by light or heat radiation; inducing magnetic effects and altering them at will; converting radiant energy directly to electrical energy, and converting electrical energy directly to light.

Many of these effects are being put to use today in practical communications devices, employing simple printed circuitry for greater compactness, ruggedness, and reliability. The most familiar examples are perhaps our portable radio sets, including transistorized personal receivers and pocket-size two-way units for commercial and public service communications. In television, the results are becoming evident in the development of fully portable personal receivers, and compact pickup equipment. In virtually all cases, the power economy of the new devices permits the use of batteries and opens the way to future application of long-life solid-state power sources such as solar batteries and thermionic or thermoelectric generators in which radiant energy is converted directly to electricity.

NEW DIRECTIONS FOR THE FUTURE

TODAY WE CAN FORESEE unlimited advance in electronic communications, recognizing that the full impact of the solid-state revolution is yet to be felt. The shape of the future in radio and television will be dictated not only by the advent of new materials and techniques, but by the general swift advance in technology as a whole.

A case in point is the recent phenomenal progress of space technology, which relies heavily upon electronic techniques of communication and guidance, and at the same time affords new methods of radio propagation.

Courtesy RCA

The transistor is symbolic of the technological revolution in electronics during the past decade. Experimental types employing a compound semiconductor material are inspected in the laboratory.

Courtesy RCA

A portent of special communications equipment for satellite relay and other space applications is this compact control unit developed for the communications system of the first Atlas satellite relay experiment in 1958.

Courtesy RCA

The forerunner of television magnetic tape recording systems for industry, defense, and the home is this experimental unit which plays pre-recorded program material from tape through a conventional television receiver.

The pioneering example of this trend is the recent Atlas "talking" satellite, which demonstrated the feasibility of long-distance microwave communications via relay equipment orbiting far above the earth.

Glancing forward over the next 25 years in communications, we may base our predictions firmly upon experimental achievements such as this, and upon the certainty that research and engineering will continue at the accelerated pace that has become so characteristic in the past decade.

The general environment of the quarter-century to come will be one in which any type of information may be transmitted over any distance, displayed or reproduced by a wider variety of techniques, or put to any desired use. Communications in this sense is an all-encompassing term, relating not only to messages or program material, but to control signals for any type of automatic process within a single system or across a broad network of many systems.

In more detail, there is a high probabilty that electronic communications will achieve such advances as these with the 25 years to come:

—World-wide television, FM radio, and microwave systems, spanning the oceans by means of satellite relay stations. For the television viewer, this will afford live programs originating in any part of the world. For the radio listener, it may bring high-fidelity, stereophonic reproduction directly from the concert halls of the world. For nonbroadcast functions, it will mean the extension on a global basis of many voice radio and facsimile-type communications now limited to overland service.

—Versatile space communications systems including radio for voice traffic and control signals, and television for remote observation. In this application, television "eyes" in satellites and space vehicles will provide versatile tools for exploration of the planets, for astronomical observation beyond the earth's atmosphere, for surveillance of weather, and for reconnaissance.

—Extensive combinations of electronic communications and data-handling equipment to program and control a multitude of automatic processes in many locations. This will be the pattern of automation in industry and commerce, and ultimately in high-speed transportation on earth, in the air, and in space.

—Personal radio systems linking individuals by two-way voice communication. Resulting from improvement of present experimental high-speed coding techniques and portable equipment, such systems will permit selective calling and private communication in the manner of today's telephone system, but with far greater flexibility.

—Electronic panel display techniques for television and radar, employing microminiature circuits and thin screens of electroluminescent material. This development may provide television receivers of the so-called "mural" type, made in any desired size for the home, the classroom, the office, and the laboratory. In radar applications, it will provide large-area displays in various colors for defense installations and airport control centers.

—Compact and inexpensive magnetic tape recording systems for color television, applied widely as a home instrument as well as a new tool of education, industry, and defense. Coupled with portable transistorized color-television cameras, this equipment will permit recording anywhere for immediate and repeated playback over the television receiver.

A listing such as this might be prolonged indefinitely, limited only by the imagination. A number of possible developments in such a list already are technically feasible but must be postponed until they may be economically justified. Others require further fundamental advance which will result from the ever-quickening pace of research and the application of research results.

The sum of these factors, economic and technical, has been the swift evolution of our electronic communications from a limited repertoire of radio techniques to a multitude of services extending over a broad range of frequencies, conveying sight as well as sound. Participating today in the general advance of all technology, our communications have entered upon a new and far more radical evolution in which these past achievements may be truly described as "a prologue to the future."

The Evolving Technology of Communication

E. I. GREEN
FELLOW AIEE

THOSE OF US who have lived through the last quarter century have experienced never a dull moment either in the kaleidoscope of public affairs or the onrush of science. Diapason has followed crescendo, and wonder has been raised to the *n*th power, until now superlatives are all but exhausted. In such circumstance, it is only fitting that we pause for a moment to reflect upon some of those factors which have affected our society most profoundly, and bid fair to do so in future. Not the least of such factors has been the progress of communication at a distance by electrical means, or if you will, telecommunication. Indeed, so interwoven have communication and social structure become that it is often hard to differentiate cause and effect. Communication begets civilization, and vice versa.

Now the rapidity of communication growth and the intensity of communication development in this and other countries have depended on a number of factors. Beyond question, however, the preponderant element has been the technological advance. Let us then address ourselves to the technology of communication, and specifically to the dual task of placing its vigorous past in due perspective and of conjecturing the major phases of future progress. If we cannot, like the Roman god Janus, face two ways at once, we can at least do like the cuckoo in the clock and look first one way and then the other. By thus looking both forward and backward, we avoid an abrupt termination at "here and now" and obtain a continuous vista—a panorama with the past etched sharply and the future sketched lightly. As for the span of years to be covered, it would be nice, had we but space enough and time, to start the story of the past with Alexander Graham Bell. However, the last quarter century will afford a satisfying bask in past achievements, and the same interval is about as far as the future is foreshadowed.

SURGING TELEPHONE TECHNOLOGY

OF THE VARIOUS FORMS of telecommunication, telephony now leads all the rest. Let us start, then, with telephony. Today, the telephone network is a far-flung, highly complex and highly integrated interlinkage that extends into every nook and cranny of the country, into practically every place of business, and almost all of the homes. This network includes some 200 million miles of wire, a length enough to reach beyond the sun. Supplementing the wire facilities is a vast array of radio systems. Substantially all of the country's telephones can be interconnected on demand, and each of them to most of the telephones outside the United States. But our present concern is not with this complex network and its myriad interdependent parts, nor even with the 25-year growth in facilities and usage—number of telephones trebled, long-distance circuit mileage up five times, number of local and long-distance calls trebled. Significant as these things are, our interest lies rather in the art upon which they have been built.

By the time our story begins, telephony had already achieved, albeit imperfectly, its epic conquest of distance, having found in amplifiers based on De Forest's three-element tube, improved with the Arnold–Langmuir high vacuum, the long-sought means for revivifying currents enfeebled in transmission over wire or radio. A good start had been made, too, on the use of carrier systems to multiply circuit capacity and thus reduce costs. Automatic switching, employing both the step-by-step system and the panel-type common control

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system, was already well established. What, then, in the way of major advances in telephone technology can be attributed to the quarter century just past? Out of the countless threads that make up the warp and woof of progress, these three are most readily discerned:

1. Immense improvements in transmission, making telephone conversation practically effortless except under very unfavorable conditions;
2. Wide expansion of the frequency range exploited by wire and radio, with large resultant economy through the mass production of circuits; and
3. The establishment of automatic nation-wide long-distance switching under control of customers, as well as the rapid spread of automatic local switching, featured by improved systems of the crossbar type.

GAINS IN OVER-ALL TRANSMISSION

THE ADVANCE IN TRANSMISSION may be epitomized by the undramatic-sounding statement that an average intercity call 25 years ago represented the equivalent of a separation of more than 35 ft between talkers, whereas for connections most commonly encountered today the average figure is in the range from 6 to 12 ft. Even this falls short of what customers would really like, i.e., the full equivalent of a face-to-face binaural conversation. Be that as may, we have come a long way in transmission improvement. In part, this has consisted in a reduction of circuit loss. In 25 years, the average loss on an intercity call has been reduced by about 10 db, which means, of course, that the customer receives 10 times the speech power he used to. But loudness of received speech is not all. Similar progress has been made in improving the quality of speech and in reducing noise, crosstalk, monkey chatter, echoes, and other bedevilments to transmission.

IMPROVEMENTS IN TELEPHONE INSTRUMENTS

THE TRANSMISSION ADVANCE has embraced many fronts and many phases. One important element has been the progressive improvement of telephone instruments to give better loudness, articulation and naturalness of speech, together with greater convenience and low cost. Examination of the telephone sets used today and 25 years ago (Fig. 1) turns up some striking comparisons. The over-all response of the set over the range of useful speech frequencies has been much improved (Fig. 2). This has been accomplished through control of resonances, and the addition of acoustical networks in both transmitter and receiver. The transmitter, in addition to acting as an electroacoustic converter, now provides an amplification of about 35 db (i.e., three thousandfold) for the impinging speech energy. Moreover, through improved balance over the frequency range, the sidetone entering the speaker's receiver has been reduced to about $\frac{1}{10}$ of the transmitter output. Besides all this, automatic equalization under control of the d-c line current adjusts the transmitter and receiver gain in accordance with separation from the central office.

CARRIER TAKES OVER

VITAL ALIKE to transmission advance and to mass economy has been a vast expansion of carrier multiplexing techniques (Fig. 3). Whereas 25 years ago carrier systems were practically limited to open-wire lines, with an upper frequency limit of about 30 kc, today carrier frequencies up to 200 kc or more are commonly used on open-wire lines and as much as 8 mc on cable.

Similar techniques have been extended to radio systems. The carrier expansion has been accomplished through (1) the systematic investigation and exploitation of different types of modulation, especially John R. Carson's single-sideband method; (2) the perfection of network theory covering filters for sharply separating

Fig. 1. The evolution of telephone sets.

frequency bands and equalizers with frequency characteristics that compensate accurately for line or other distortion; (3) the development of competent circuitry; and (4) a thoroughgoing analysis of the complex behavior of communication currents. As a result, carrier circuits (either wire or radio) now comprise most of the long-distance telephone circuit mileage. The most intensive use of carrier techniques on cable is found in the coaxial cable system, which provides, on a single coaxial consisting of a small copper tube and centrally supported wire, a frequency band nearly 8 mc wide. Two such coaxials can provide either (1) 1,800 telephone channels or (2) 600 telephone channels plus a 4.2-mc television circuit in each direction.

A cardinal feature of modern carrier systems is their use of different paths for opposite directions of transmission. This four-wire (or equivalent) principle obviates the need for balance at repeaters, thus minimizing intermediate echoes and permitting lower circuit losses. Of basic importance in the gradual improvement of speech transmission was the adoption, just a quarter century ago, of a gross bandwidth of 4,000 cycles as standard for a carrier telephone channel.

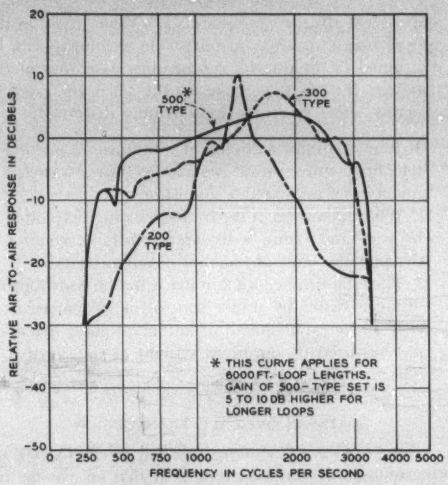
RELATIVE AIR-TO-AIR RESPONSE IN DECIBELS
FREQUENCY IN CYCLES PER SECOND
500* TYPE
300 TYPE
200 TYPE
* THIS CURVE APPLIES FOR 6000 FT. LOOP LENGTHS. GAIN OF 500-TYPE SET IS 5 TO 10 DB HIGHER FOR LONGER LOOPS

Fig. 2. Response characteristics of telephone sets.

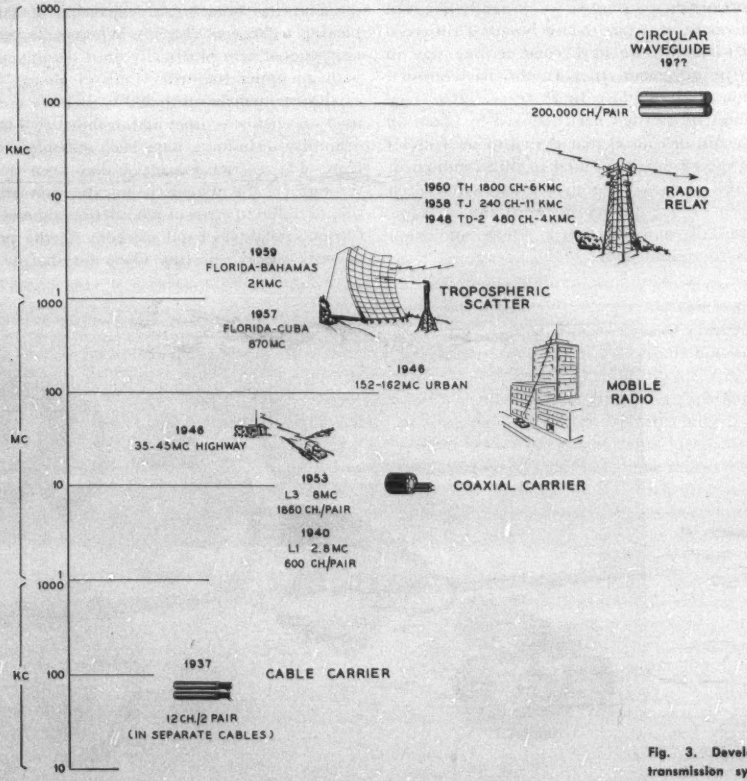

Fig. 3. Development of transmission systems.

THE ROLE OF VACUUM TUBES

THE BASIC BUILDING BLOCK for the transmission advance has been the vacuum tube, diversely modified and vastly improved from the original De Forest–Arnold version, and ubiquitously applied for the various functions of frequency generation, amplification, detection, and frequency translation. Better understanding of physical principles, together with the development of much improved materials and processes, has yielded multielectrode tubes especially adapted for high-frequency use, much extended life (up to 10 or 20 years of continuous operation), greatly reduced activating power, and numerous other improvements. Moreover, the vacuum tube has afforded the means for the precise measurements that were required to establish a firm foundation for the transmission art—measurements of transmission circuitry and systems, and of transmission defects such as distortion, noise, echoes, etc.

NEGATIVE FEEDBACK—THE KEY TO PRECISE AMPLIFICATION AND CONTROL

AN INDISPENSABLE INGREDIENT of the transmission advance, second only in importance to the vacuum tube itself, has been the negative feedback amplifier. Following the invention by Harold S. Black in 1927, elucidation of the underlying theory and development of circuit techniques for widespread application came about during the period under review. By the seemingly simple device of feeding a part of the amplifier output back to the input in negative phase, distortion and instability are reduced by a factor of a thousand or more. Here was the made-to-order answer to the urgent problem of controlling, to exquisite perfection, the amplification of great numbers of tandem repeaters each handling a multiplicity of channels (likewise the ideal means for other kinds of precise control).

Today, a conversation over a long transmission circuit may pass through as many as a thousand amplifiers, including a total of 12,000 vacuum tubes and 400,000 other elements such as transformers, inductors, resistors, capacitors, quartz crystals, and what not. The total amplification introduced in the circuit may be of the order of 40,000 db, or an amplification ratio of $10^{4,000}$. For comparison with this superastronomical figure, the ratio of 15 billion light-years (which is as far as the new radio telescope at Big Pine, Calif., can reach) to the radius of a small nucleus is only 10^{39}.

MASS PRODUCTION OF CIRCUITS

THE GROWTH of long-distance telephony has been the result, in no small measure, of what may be termed the mass production of transmission circuits. Multichannel carrier and radio systems divide the cost of a transmission path among a large number of circuits. Also, concentration of many transmission paths on the same route yields further large economies through the sharing of common elements of cost such as power supply and right-of-way. Indeed, there seems to be a rough sort of economic law that applies broadly to these situations. If the number of circuits on a route is multiplied by ten, the line cost per circuit is divided by about five. Sometimes, after considerable stress and strain, new developments may go this relation slightly better. Other times, with equal stress and strain, they fall a little short. In any case, substantial economies have been realized through large concentrations of circuits on long distance routes, demonstrating the wisdom of Andrew Carnegie's advice to "Put all your eggs in one basket, and watch the basket."

THE GROWTH OF RADIO

RADIO, STILL IN ITS INFANCY 25 years ago, has been fashioned into a powerful instrument for point-to-point, mobile (including motor vehicles, trains, ships, and airplanes), and broadcasting communication. Through meticulous study of the phenomena of propagation in different frequency ranges, and multifaceted development of effective transmitters, receivers, and antennas, formerly limited use of the spectrum up to about 30 mc, has been expanded to 11,000 mc, or thereabouts.

Initial radio experiments based on direct propagation were soon followed by ground wave transmission, including the effects of ground reflection and of refraction by the troposphere (i.e., the inner part of the earth's atmosphere, where temperature generally decreases with altitude, clouds form, and convection is active). Starting only a little more than a quarter century ago, transoceanic communication has made extensive use of short-wave frequencies (3 to 30 mc), with propagation by reflection due to ions and electrons in the ionosphere. As techniques have been extended to higher frequencies, increasing use has been made of different kinds of propagation for a variety of purposes.

A quarter century ago, repeatered radio systems capable of transmitting wide frequency bands were merely envisioned. The large-scale development during World War II of radar (itself a form of communication) in the kilomegacycle (or so-called microwave) range gave a powerful stimulus to the postwar development of radio relay systems, using line-of-sight transmission. Today, these provide about a third of the long-distance telephone circuits in the United States and most of the television network facilities.

A new method of propagation that makes use of scattering (i.e., reflection) from discontinuous layers in the troposphere yields substantial communication bandwidth with relay stations a few hundred miles apart. This is valuable in situations where geographical considerations make closer spacing of stations impossible or prohibitively expensive. Ionospheric scatter is being used for narrow communication bands, and meteor reflection intermittently for the same purpose.

Out of radio communication, moreover, have come countless contributions to other science and technology. Radio astronomy, stemming from Karl Jansky's discovery of static coming from the Milky Way, is yielding new knowledge of the universe, unobtainable by other means. Radio techniques are being employed in the treatment of disease, in cooking and food preservation, and in various scientific and industrial processes.

THE QUINTESSENCE OF RELIABILITY

OVERLAND CARRIER TECHNIQUES for broad-band multiplexing with high reliability have been brought to their greatest perfection in transoceanic telephone cables with multiple submerged repeaters designed to operate continuously and flawlessly, at depths up to 2,000 fathoms, with no attention for at least 20 years. After an initial application between Key West, Fla., and Havana, Cuba, in 1950, a transatlantic cable of this type was placed in service between Newfoundland and Scotland in 1956, with others following and still others in prospect. The secret of success in such an undertaking lies in the utmost care and exactitude throughout the entire course of development, manufacture, and installation.

SIGNIFICANCE OF INFORMATION THEORY

PROGRESS IN DIFFERENT BRANCHES of communication has been furthered by the formulation of a comprehensive mathematical theory underlying the communication of information. This theory, developed by Claude E. Shannon, Norbert Wiener, and others, states in essence that information of the kind transmitted over communication systems is measurable as to quantity. In consequence, the loss of information caused by perturbations occurring in transmission can be evaluated. The basic unit of measure is a "yes or no" choice, called a bit. All information can, for communication purposes, be expressed as, or encoded into, sequences of binary pulses, each representing one bit of information. The basic theory makes it possible to treat such transmission factors as bandwidth, noise, distortion, and the like on quantitative terms, which facilitates the comparison of different transmission systems, with different forms of modulation, coding, etc. The theory does not in itself provide new techniques, but greatly facilitates their appraisal.

AUTOMATIC SWITCHING—FOUNTAINHEAD OF COMPUTER TECHNOLOGY

PARALLELING THE PROGRESS in telephone transmission has been an equivalent advance in the systems for telephone interconnection. Years before the word automation was coined, the automation of telephone switching began. It started slowly, however. Twenty-five years ago most of the switching was still done by operators. Stimulated by the awareness that growth would carry the demand for operators far beyond the number obtainable in our society, automatic switching has been extended until today the great bulk of the local switching is accomplished automatically, hence faster, more accurately, and more economically.

One feature of this metamorphosis has been a new crossbar system, specially adapted to urban and suburban applications. Other crossbar systems have been perfected for tandem and long-distance use. The most sophisticated of these makes connections on a two-path (or four-wire) basis, yielding better transmission performance for multilink connections. All of these systems operate on the principle of common control, which means that incoming pulses are temporarily stored in a device which then controls the switches directly or indirectly. Such systems have great flexibility and efficiency in the use of trunk groups and are especially advantageous for large exchanges and for the automatic routing of long-distance calls.

The most recent embodiment of automatic switching is nation-wide dialing by customers without the aid of operators. This interlinkage of telephones gave rise to the comment by Francis Bello in *Fortune* that "it is now clear that what the Bell System has been doing is . . . building the world's largest computer." In nation-wide dialing, the switching mechanism selects the route to the distant telephone. Should it find direct circuits busy, it explores in succession a number of alternate routes, and establishes the connection over the least circuitous path available. Since no operator is required on a directly dialed call, billing information is automatically recorded for later processing.

BROADCASTING TAKES SWAY

THE QUARTER CENTURY has seen a striking evolution in another form of communication, a form so familiar that we sometimes forget how recently it came into being. This is the diffusion of entertainment, information, advertising, or propaganda by radio; in a word, broadcasting. Broadcasting of sound programs, which began in 1920, has spread over the entire country. But it was the combination of vision with sound that brought to broadcasting its greatest public interest and social import. Crude television concepts date back to the 19th Century. However, the era of practical television broadcasting had to await the perfection of electronic techniques for scanning and reproduction, and did not get well under way until after World War II. Today, there are about 40 million receiving sets, served by some 500 transmitters interconnected by 80,000 miles of wire and radio circuits, each of which occupies a frequency band a thousand times as wide as a telephone circuit. Color television, which is technically more difficult because with present techniques less amplitude and delay distortion of the signals can be tolerated, is slow in gaining public acceptance.

TELEGRAPHY ON ITS WAY

TELEGRAPHY, despite a 30-year head start, has not grown as fast as its younger sister, telephony; nevertheless, the interval has seen substantial advances. Machine operation with teletypewriters has taken over, and the old Morse key and sounder are virtually extinct. Exchange teletypewriter service has just celebrated its 25th anniversary. Telegraph multiplexing, the quest for which led Bell to invent the telephone, has ranged over the same general area as telephone multiplexing. With the usual 60- to 100-word-per-minute transmission, the frequency band occupied by a telegraph circuit is only about $\frac{1}{10}$ to $\frac{1}{20}$ that of a telephone circuit. However, the rate of information passage over such a telegraph channel is about a third or a half that for a telephone channel (excluding naturalness).

PICTORIAL SERVICES

Related to telegraphy are several kinds of services that have come into being for transmitting some sort of permanent or semipermanent pictorial matter over a distance by electrical means. Facsimile, in which the picture consists merely of black and white values, has found important civil and military uses for sending weather maps, diagrams, symbols, advertising matter, and the like. Telewriting, in which writing movement at the transmitting end causes corresponding movement of a writing instrument at the receiving end, has found modest use in railroad terminals, airports, factories, and restaurants. Telephotography, that is, the transmission of pictures with a gradation of shade values, has become well established, and a nation-wide network is provided for the news services.

RISE OF THE ELECTRONIC INDUSTRY

So much for prologue. In taking leave of the past, it is pertinent to note that the underlying techniques whereby communication has become a multibillion dollar industry have given birth to other electronic industries, including entertainment, data processing, industrial control and instrumentation, and military electronics, whose volume in total exceeds that of communication itself.

THE MIST OF THE FUTURE

All down through the ages, man has aspired to don the prophet's mantle, and pierce the mist of the future. Indifferent though his success may have been as to affairs in general, he now finds it possible to exercise considerable divination in the field of science and technology. For here, as nowhere else, do coming events cast their shadows before. Here the future, at least for a modest span, is man's to envision and in fair measure to plan, if only he has the wit to do so. In part, this means simply taking advantage of the fact that the proximate future behavior of a dynamic system is roughly predictable from observation of its proximate past behavior. Even so, some difficulties enter. For any new technology, utility is the real touchstone. Yet marketability and profitability are much less predictable than technical feasibility. Furthermore, it is not easy to differentiate the technology that will be achieved in such a small segment of time as the next quarter century from that which is sure to come in the long run. But we can at least try.*

A HOST OF NEW INSTRUMENTALITIES

Just as De Forest's audion, converted into a vacuum tube, ushered in the communication era just past, so the sign manual of the era just beginning to unfold is the transistor of Bardeen, Brattain, and Shockley. Wonderful and useful as the vacuum tube is, it has serious limitations. The transistor affords much higher amplifying efficiency because it wastes no power in heating a cathode. Also, it uses much lower electrode voltages, is much smaller, and will afford high reliability and long life. Moreover, the associated electronic components can be made almost as tiny as the transistor itself. The over-all result is that the size, weight, and power consumption of apparatus employing transistors can ordinarily be reduced to a small fraction of that for equivalent vacuum tube apparatus. Altogether, this means that transistors are going to find increasingly numerous and varied applications in almost every field of communication, including not only situations where vac-

*All opinions regarding the future are those of the author.

KEY:
1. 4. 7. 8. 9. — TRANSFLUXORS
2. FERRITE CORE
3. 5. 6. 10. — LADDICS
11. FERRITE SHEETS, SHOWING PRINTED WIRING
12. DISTRIBUTED CONSTANT ELECTRICAL DELAY LINE
13. LUMPED CONSTANT ELECTRICAL DELAY LINE
14. MATRIX OF EVAPORATED MAGNETIC FILMS
15. VITREOUS SILICA ACOUSTIC DELAY LINE

Fig. 4. Some memory devices.

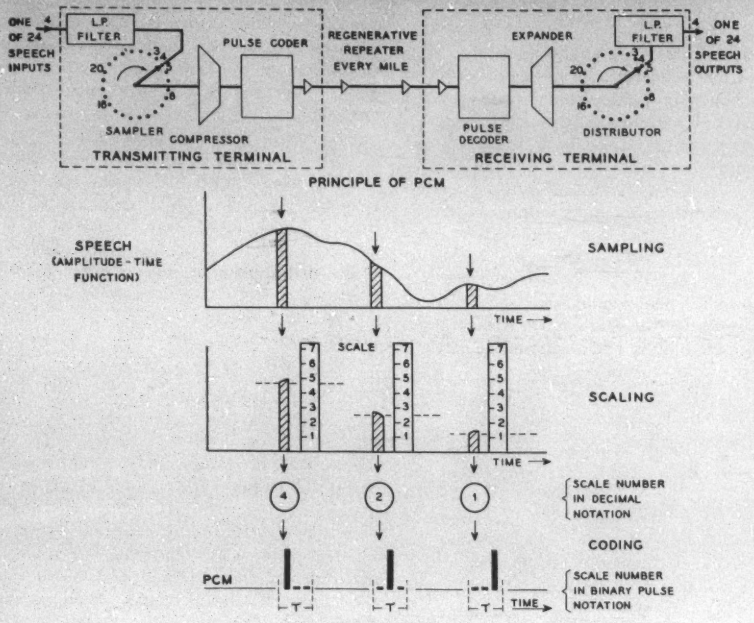

Fig. 5. Pulse code modulation.

uum tubes were previously used, but many new situations as well.

However, the transistor is just one (albeit the preeminent one) of a host of new electronic building blocks, either in being or yet unborn, out of which the communication technology of the future will be fashioned. The variety of new devices stemming from increased understanding of solid-state physics, ferromagnetism, microwave resonance, etc., and from fundamental study of new materials and their properties, is too great and too ingenious for even casual treatment here.

There is, however, one fast-growing category deserv- of brief mention, namely, memory devices (Fig. 4). Communication systems of the future (and other electronic systems as well) will derive increasing versatility, speed and effectiveness from three kinds of memory: (1) semipermanent memory, for translation or stored program; (2) temporary memory, for preserving "in-process" or newly accumulated information; and (3) transitory memory, for delay, timing, phase equalization, etc. Bits of information (sometimes numbering up to millions or billions) will be stored in photographic plates, tiny ferrite cores, twistors (stressed magnetic-coated wires), ferrite sheets, barrier grid tubes, magnetostrictive delay lines, etc. Wherever necessary, access to the stored information will be had in a microsecond or less. In laddics (tiny multipath ladder-like pieces of ferrite), memory will be combined with logical judgment (i.e., Boolean algebra). All of this, combined with the transistor and other new devices, will make it possible to secure information, make decisions and complete operations in a minimum of time, with resultant over-all system economy.

TELEPHONE TRANSMISSION PROSPECTS

With this backdrop of new device technology, let us take a forward look at some of the areas previously considered. What about transmission performance in general?

We can expect considerable further improvement, both in the raising of objectives and in the reduction of departures from accepted objectives. This advance will result from a combination of better facilities (e.g., improved long- and short-haul carrier systems, greater use of four-wire toll switching, extension of carrier into the exchange plant, etc.) and better maintenance techniques. As a result, telephone calls, in general, will come closer to being the full equivalent of a face-to-face binaural conversation.

COMING TELEPHONE INSTRUMENTS

Distributed along the path of the future will be a series of increasingly attractive and convenient telephone sets, including diminutive sets, dial-in-handset, pushbutton signaling, repertory calling, and the like. Although further improvement in transmission properties is to be expected, the advance which has been

made during the last quarter century has been so large as to leave no room for a comparable one in future. Hands-free telephones employing a microphone and loudspeaker are becoming more and more popular because of their convenience. Even when full advantage is taken of voice-switched gain, room acoustics constitute a major challenge to making the performance of such a set comparable to that of a handset held close to mouth and ear. And room acoustics are an even greater problem where microphones and loudspeakers are used for conference connections between separated places.

THE COURSE OF RADIO

IN THESE TIMES TO COME, radio will expand and improve. Traveling-wave tubes will yield wide-band amplification at higher frequencies. Better noise figures will be available from masers, parametric amplifiers, etc. Isolators from new ferromagnetic materials will reduce pulling and crossmodulation. Transistors and other solid-state devices will be pushed up in frequency, power output, and reliability, so that very small radio devices will become common, economical, and trouble-free. "Tougher" modulation methods such as pulse-code modulation with regenerative repeaters, will afford greater reliability. New types of highly selective antennas, such as horn reflectors, loaded dielectrics, etc., will reduce noise and interference.

Ingenious ways will be found to utilize the radio spectrum more effectively. Just on the horizon, for example, is a new 6,000-mc relay system which uses frequency space more than three times as efficiently as present systems. However, the usable radio spectrum is finite. Rain attenuation and atmospheric absorption seem likely to restrict long-distance usage to some frequency below 20,000-mc, though higher frequencies may find application for very short distances.

Growing congestion in the radio spectrum will lend special emphasis to those services where radio is essential or nearly so—to wit, mobile service and broadcasting. We may expect that a more effective public mobile telephone service, especially to motor vehicles, will be provided through intensive multichannel use of substantial blocks of frequencies with the aid of channel sharing and co-ordinated techniques. Radio paging of individuals on the move promises to find greatly increased usage.

TRANSMISSION BY PULSES

FUTURE TRANSMISSION progress will very likely be in the direction of digital rather than analog techniques. Speech and other signals will be multiplexed by pulse methods, with channels interleaved in time instead of frequency. Indeed pulses bid fair to be the heartbeats of the new communication era. The most promising of pulse modulation methods is pulse code modulation (PCM), in which successive samples of the signal wave are transmitted by an extremely high-speed telegraph code (Fig. 5). The pulse code method provides, at the expense of bandwidth, low vulnerability to interference, and makes it possible to regenerate the pulse signals perfectly at each repeater, so that there is no accumulative distortion. Thus, the time-honored problems of noise and crosstalk may be overcome, and attention focused on new ones centering in synchronization and delay correction. Field experiments are already

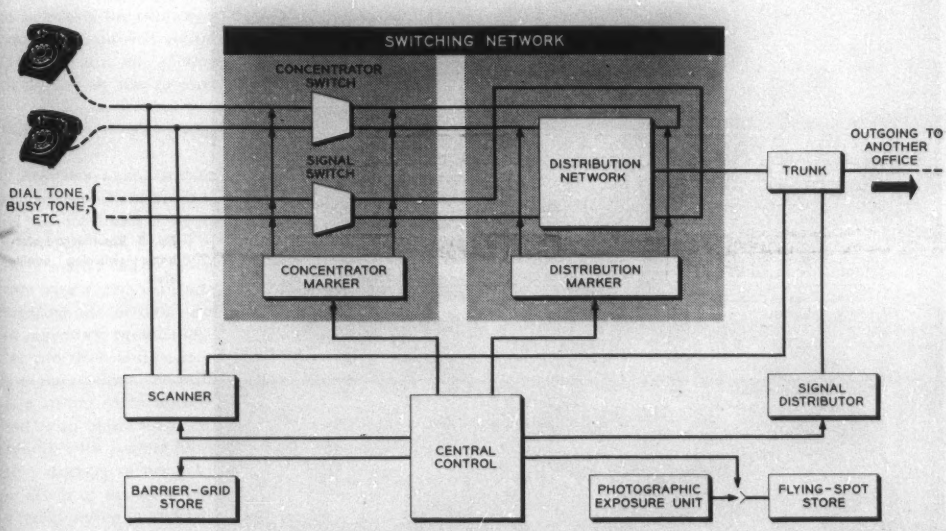

Fig. 6. Block diagram of electronic switching system.

under way on a PCM carrier system for the exchange trunk plant.

ELECTRONIC SWITCHING

We may expect a rapid extension of the automatic switching of long-distance calls, making this service available to nearly all telephones. But far more radical things are in store. Switching is just beginning to feel the full impact of the new electronic art. All of the automatic switching systems up to now have been built around the electromagnetic relay and other electromechanical devices. Such devices are, in modern terms, quite slow; they require a minimum of several thousandths of a second to operate. In contrast, electronic devices such as the transistor will perform switching or complex operations in a few microseconds.

New switching systems will profit from this high speed through centralizing of functions and time-sharing of the computer and control apparatus. Interconnections will be effected by either space or time division, or a combination of the two. In contrast to an electromechanical switching office, where all instructions had to be wired into the equipment, the electronic office will afford a high degree of versatility through programs stored in memory (Fig. 6, 7, 8). Thus, it will be possible to redistribute switching functions for maximum economy. Such features as simplified codes for reaching frequently called telephones (wherever located), subsequent automatic completion of calls to a busy line, automatic transfer of incoming calls to a specified telephone, automatic centralized answering service, and the like should become commonplace. A

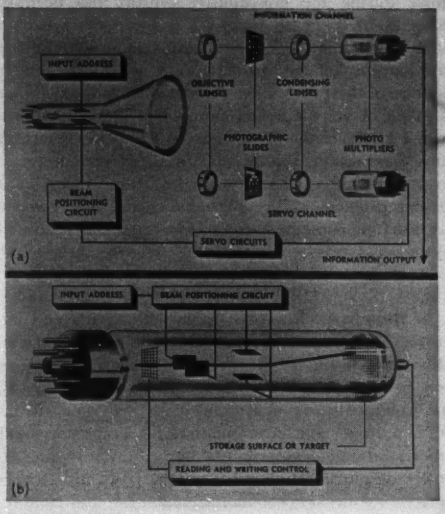

Fig. 7. Permanent (a) and temporary (b) memory for electronic switching.

Fig. 8. Experimental electronic switching equipment.

further feature of the electronic switching systems will be provision for self-testing.

The merging of switching and transmission through common use of pulse techniques is an interesting possibility, and may come into practical use toward the end of the period of this forecast.

VISUAL INFORMATION

In pictorial systems, such as facsimile, telephotography, and the like, further perfection of technology is to be expected, along with further growth. The future of television, however, is more intriguing. In fact, the transmission of visual information promises to assume much greater importance and may become the overall determinant in future communication techniques and facilities.

In television broadcasting, a considerable shift to color is to be expected, together with improved transmission stability, reduction of multipath effects, and better operability and reliability of receiving sets. What will happen in pay-as-you-see television is anybody's guess. Large-screen theater television remains an economic enigma. Special-purpose apparatus, some of it of the slow-scan type, will contribute to increased use of closed-circuit television for industrial and business purposes, including the inspection and control of processes, and personnel and signature identification. To a large extent, the techniques needed for educational television are already at hand, and the future looks bright indeed. The technological problems involved in combining television with telephony, so as to provide as nearly as possible both the visual and aural equivalent of face-to-face conversation, are surmountable but by no means simple, particularly those of switching the two-way speech and vision all over the country. Improved technology should afford a more favorable economic picture, and some application seems likely during the 25-year interval.

DATA COMMUNICATION

Another large source of future requirements for transmission bandwidth will be data communication in its various forms. The information to be transmitted will range from textual material to numeric and alphabetic matter, all represented by pulse codes. Much of the anticipated demand will come from the rapidly growing use of data processing in the mechanization of inventory, production, payroll, accounting, and similar processes, and in services to the public such as airline reservations, centralized charge accounts, etc. There is a strong trend toward electronic computing centers fed with data from auxiliary machines at outlying points, with process results distributed either locally or to a distance as needed.

Much of the data will be transmitted at low speed, corresponding to human generation and utilization, but higher speeds will frequently be required for efficient use of transmission channels, particularly voice channels. It is expected that much of this traffic will be handled by existing types of voice or telegraph channels. Switching may be accomplished by the voice switched network (so called dataphone service) or with special switching centers, or both. New technology will be needed both for dealing most effectively with terminal problems of error correction, synchronization, speed and code conversion, etc., with transmission problems due to impulse noise, delay distortion, etc., and with switching problems, and also for realizing maximum economic attractiveness.

WAVEGUIDE SYSTEM

In view of the clearly foreseeable need for much greater information-carrying capacity on major communication routes, exploratory work has been under way for a number of years on a waveguide transmission system. The transmission medium will be a hollow copper pipe or helix about 2 inches in diameter, acting as a guide for radio waves traveling inside (Fig. 9). The system will employ the circular electric transmission mode (TE_{01}) which has the unique property of decreasing attenuation with increasing frequency.

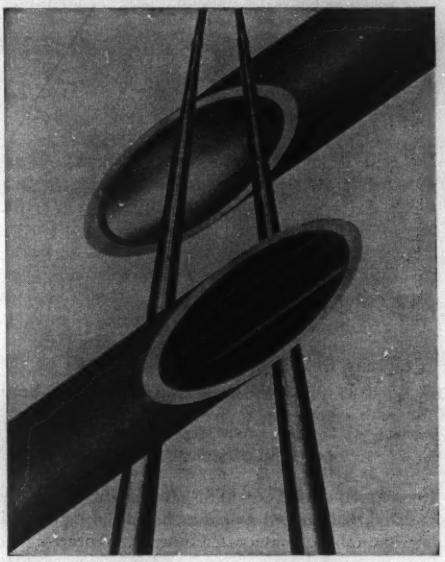

Fig. 9. Waveguide for circular electric mode transmission, solid and helical wall.

The frequency band transmitted inside the pipe may range from 35 to 75 kilomegacycles, i.e., a gross band nearly four times as wide as the entire band now used for all radio communication. The waveguide will,

Fig. 10. Rigid repeater for submarine cable (artist's rendering).

therefore, yield a vast frequency spectrum not vulnerable to fading, atmospheric effects, interference, or other troubles that beset the radio, and not subject to public demands and consequent governmental restrictions. Within this frequency band, a large number of broadband channels, each filled with millimicrosecond pulses, will provide a handling capacity for tens of thousands of voice circuits or hundreds of television pictures. It now seems highly probable that the enormous transmission capacity will be needed on many routes by the time it can be made available, 10 years or more from now.

GLOBAL COMMUNICATION

INTERCONTINENTAL COMMUNICATION will be greatly stimulated, and indeed metamorphosed, by repeatered submarine cables. Underwater transistor repeaters will eventually replace the vacuum tube variety. Cables capable of handling much wider frequency bands will be developed (Fig. 10), giving more telephone channels and making it possible to transmit television across ocean barriers to the extent that there is economic or military justification. For some time to come, the high cost of submarine cable facilities will lend attractiveness to "band-saving" techniques (such as the TASI system for interleaving voice spurts and thus taking advantage of the silent intervals in a two-way conversation). Intercontinental dialing (or button-pushing) will come into being, first from operators to customers, and later between customers.

Space communication by radio will develop. Space vehicles, whether manned or no, and whether or not as important as enthusiastic proponents now imagine, will employ radio for communication and guidance. Communication via satellites between widely spaced points on earth promises to become a reality, particularly for military purposes. Reasonably acceptable communication by means of reflecting systems using a number of satellites with a period of a few hours (i.e., at a distance of 2,000 to 3,000 miles above the earth) is probably realizable with only moderate extension of existing art. A 24-hour satellite (i.e., some 23,000 miles above the earth) with an active repeater seems to be a more interesting long-range possibility. Aircraft guidance by means of satellite radio likewise has possibilities.

The need for effective control of military organizations and operations on a far-flung basis will place increasing emphasis on global networks for military communication in the years ahead. These networks will include all kinds of interlinkages and will handle all kinds of signals—aural, visual, pictorial, telegraphic, high-speed digital, etc., with requisite speed reliability, and security. Some of the most striking technological advances of the period may stem from military necessity.

CONCLUSION

HERE we must close. Though it cannot be precisely delineated, the future of communication promises to be even more brilliant than the illustrious past. It may be appropriate to echo the words of Thomas Jefferson: "Hats off to the past; coats off to the future."

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Advances in Communications

H. I. ROMNES
FELLOW AIEE

"THERE ALWAYS is a better way," underlies the spirit of service to the nation which has been the precept of the telephone industry from its beginning.

In the late 19th and early 20th centuries, it was a common occurrence for authorities in many scientific and engineering fields to declare that all the basic discoveries had been made and that the universe was well ordered and understood. All that future generations had to do was to work out some minor details and be ultra-careful in their use of natural resources. Advances in technology, new materials, and refusal to be content with "the way it's always been done" have confounded these prophets of two generations ago.

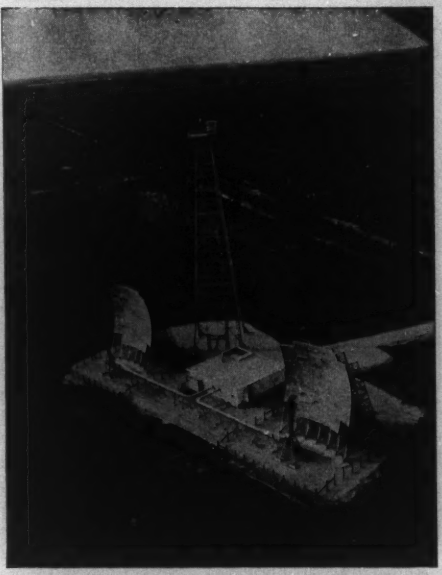
Of course, not all men of repute were saying that all the great discoveries had been made. In May 1934, when the AIEE celebrated the 50th Anniversary of its founding, the contributors to *Electrical Engineering* looked upon the future with bright optimism in the belief that even greater advances were to come. In communications, the predictions of carrier systems for cable plant, the transatlantic telephone cable, and a commercial television network have all been fulfilled. In fact, much more has been done, though the basic communications problems as described by Bancroft Gherardi in 1934 remain the same:

1. Equipment is needed to change sound, electric pulse, or other energy into electric waves and back again.
2. Switching systems are needed to connect quickly and accurately any two telephones or other communication equipment.
3. Means are needed to transmit electric waves over any distance without undesirable distortion or attenuation.

These three problems are so basic to the telephone industry that a large part of its research and development effort is still concentrated on them.

In a changing world, the telephone industry has also had to change. In fact, it has actively pursued change when this meant advancement and progress which could lead to better service and more efficient operations. Changing preferences of customers, technological advances, and the competition of the market place have kept the telephone industry on the move in its increasingly complex multimillion customer job. Better ways, new ways are the order of the day and of tomorrow too.

H. I. Romnes was vice-president of the American Telephone & Telegraph Co., New York, N. Y., when this article was written; on March 17, 1959, he became president of Western Electric Co.



Over-the-horizon radio transmission is a means of transmitting radio signals long distances without use of intermediate repeaters. In this Florida installation, the large antennas send and receive telephone conversations and television programs 185 miles between the United States and Cuba. Horn reflector antenna installed on tall tower connects station with nation-wide network.

A GENERATION OF GIANT STEPS

IN REVIEWING the accomplishments of the communication arts for that 50th Anniversary issue, Bancroft Gherardi firmly expressed the belief that even greater developments were on the way. So fully has this belief been justified, that the advances in the art of communication over the last 25 years can be summed up as "a generation of giant steps."

Tremendous strides have been made in every phase of the telephone industry. The post-depression years, the challenge of the war-time years and the astonishing post-war growth of the Nation have put the telephone industry on its mettle as never before. Telephone service has grown from a service used mainly for necessary and emergency calls to a regular part of contemporary living.

The telephone instrument itself, in its variety of practical applications, is now a thing of utility *and*

	1934	1959
Total telephones in the U. S.	17 million	70 million
% dial	48%	96%
Total telephone messages	19 billion	68 billion
Long Distance telephone messages	415 million	3,000 million
Miles of Long Distance circuits	8 million	63 million
Customers using Direct Distance Dialing	—	25 million
Daily overseas conversations	63	5,000

Numbers tell a story.

Speakerphone (hands-free telephone) service is current offering of Bell System. As experimental step toward more compact, modern packaging of speakerphone equipment, a trial model of 6-button Capri is shown. Microphone-dial unit has associated speaker, and may have handset separately mounted somewhere in desk for privacy if desired. Field trials of Capri begin in 1959.

beauty. Carrier modulation techniques, barely out of infancy a generation ago, now provide most of today's circuits on wire cable, coaxial cable, or microwave radio relay systems. Speech or other communication is now transmitted more reliably and truly than ever. Most telephone calls are automatically completed with a speed and accuracy not possible with manual operation. Customers in many cities now directly dial calls to distant places, coast-to-coast and border-to-border. Although voice communication is the bread and butter of the telephone industry, a variety of closely allied communication services are available to fill the specialized needs of individuals, governmental agencies, and commercial enterprises.

ON STAGE

THE TELEPHONE instrument itself, in most cases, is the only visible part of telephone service—it is on stage while the vast amount of electric and electronic gear works behind the scenes. But just as the telephone user more and more takes for granted the ease and convenience of the service, more and more he also expects that his telephone—the symbol of his service—will be kept modern.

The latest type of telephone has a handset which is light in weight and easy to pick up and use. It has a bell which may be readily adjusted for loudness. It comes in many colors. Illuminated dials, pushbutton selection of extensions, hands-free arrangements, automatic answering and recording devices, are all available. Special telephones for the hard of hearing, for very noisy locations and for places which involve explosive atmospheres can all be supplied. A small telephone to fit nicely on a bedroom night table or other small surface is soon to be offered. Testing is now finished and manufacture has begun of a complete home communication system for easy room-to-room telephoning, as well as for connection to the world-wide tele-

Telephone companies are now providing two types of telephone answering sets which automatically answer incoming calls. One type transmits recorded announcement to party calling advising when to call back. Second type gives recorded announcement and also permits caller to leave recorded message.

Modern design console is new production model of call director used for signaling, pick-up, and hold. Six-button units can be added or changed on plug-in basis. Sets are available in various colors and two sizes having maximum capacities of 18 or 30 push buttons respectively.

Considerable design work on new telephone sets resulted in models shown which will be on trial or in production before end of 1959. Features incorporated and being evaluated are reduced size, improved appearance, recessed mounting, dial-in-handset, push-button dialing, chime ringers with switch for loud ringing bell, hands-free operation, and improved transmission.

phone network. Similar convenience, small size, and pleasing appearance are designed into a key-operated office communications system for the professional man or small business.

DOWN WITH DB'S

THIS IS the sign of progress for telephone transmission engineers—reduction in the decibel (db) loss in a telephone connection. They know that the communication service which most nearly approaches the ideal of face-to-face conversation will be the most used. Time and time again, each step toward the ideal of transmitting the voice naturally and at normal speaking levels has stimulated the use of the telephone and brought with it the need for more and more circuits to more and more places. For example, when the first ocean cable was placed in service to supplement the radiotelephone, in 3 months the number of calls the public wanted to make per day to and from Great Britain increased more than in all the previous 25 years.

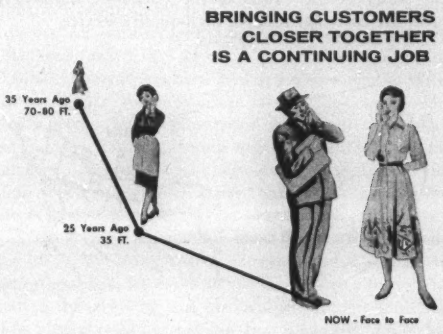
Telephone engineers have made tremendous advances in facilities which provide both more circuits on a route and more faithful transmission of the human voice, and the end is not in sight.

For circuits of considerable length, cable carrier was a big step forward in the late 1930's. By the principle of modulation, with appropriate filters, 12 circuits could be provided on the same copper wires that previously could furnish only one or two circuits. This advance was of inestimable help in meeting the communication demands during World War II, for it permitted a large increase in circuits with, at the same time, drastic reductions in the use of vital war materials.

Today, there are a variety of cable carrier systems which suit the requirements for various quantities of circuits of different lengths. Where there is a need for huge numbers of circuits, such as between New York and Philadelphia (or for that matter, from the East Coast to the West Coast), the coaxial cable is extremely useful. Originally placed in service in 1941, it first could provide a few hundred circuits per pair of coaxial tubes and now on many routes, provides 1,800 circuits per pair of coaxial tubes, of which there are four pairs in a typical cable. Coaxial cables are also used in parts of the network which provide commercial television.

Shortly after World War II, trials of a radio relay system operating in the microwave region proved successful. This gave the nation-wide telephone network another means of obtaining huge numbers of telephone circuits as well as channels for television network service. Radio relay permitted new routes to be built over terrain otherwise very difficult for cable installation, and it also provided a means of facility diversification, so necessary to keep communication services reliable and as free of interruptions as human ingenuity can devise. Microwave systems, providing a wide range of circuit capacity, are now used for both long and short distances.

In designing circuits of nominal length such as subscribers' loops and trunks between local exchanges, telephone engineers have used enormous quantities of smaller gauge conductors to save copper and dollars. The development of inexpensive high-quality amplifiers and telephone sets which need less power to do their job of transmitting and receiving the human voice have made this possible. The use of carrier techniques for circuits of nominal length has not developed as fast as for cross-country circuits. For one thing, fewer miles of copper can be saved. Therefore, the carrier system terminals must be much cheaper than those in use for longer circuits. A major step forward in this direction has made equipment available which



Artist's sketch shows improvement in long-distance transmission over the years as equivalent distances in air between talkers without telephones. Telephone transmission is continually being improved.

(Left). Conventional way of distributing telephone and power facilities is by means of poles and overhead wires. *(Right).* Distribution cables are now being installed underground on an experimental basis at some large housing developments where soil conditions are suitable. Poles and overhead wires are not needed as telephone men, using new type trencher, install distribution cable down an easement.

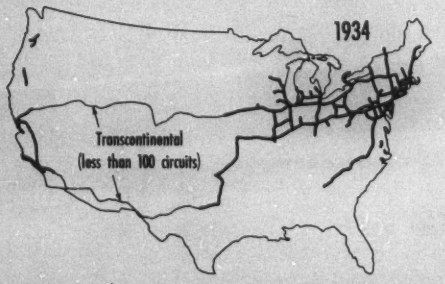
greatly improves the economy of using carrier for trunks between nearby exchanges. As a result, the production of carrier equipment has reached levels undreamed of a few years ago. Technology using semiconductor devices is also beginning to show bright promise for even further economies.

Reliability is a prime requisite of communication service. A lot of reliability is built in during design and manufacture. Protection against the elements is furnished in considerable measure both by putting cable underground and by using radio. Moisture in a cable is guarded against by a dry gas under pressure with an automatic alarm to indicate a break or puncture. Coaxial cables and microwave radio relay systems are arranged for automatic transfer of service from a channel in trouble to a good one. The list is a long and continuing story of the efforts of the telephone industry to give the customer reliable high-quality service.

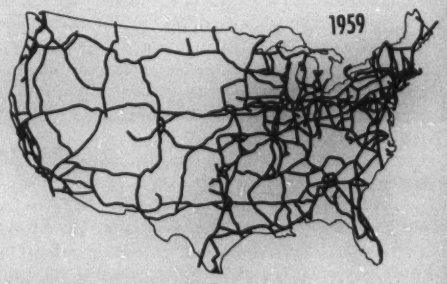
EDUCATING THE SWITCH

Soon after the telephone was invented, it was found that a centrally located switching arrangement was necessary if any two telephones were to be connected together. At first, switching was a purely manual operation at "central" on the oral request of a customer. Before many years, however, a mechanism for automatically connecting any two customers of the same central office was invented and applied. This mechanism, known familiarly to a great many telephone people as a "step-by-step" switch, was improved and made more versatile over the years. It is still used very extensively, even though more sophisticated mechanisms have since been developed to take its place in many applications.

This sophistication has been provided by designing a sort of "educated" switch to provide automatic connections. This was accomplished by introducing a memory function and logic function, much in the fashion



Demand for intercity communication services grows with economic and industrial progress. Maps illustrate increase during past 25 years in intercity telephone routes carrying 100 circuits or more.



Innumerable routes carry less than 100 circuits and a variety of transmission systems are used in network. More than one type of system is utilized on many of the routes shown.

of today's computers. A part of the mechanism was made to remember the number dialed, among other things. Another part of the mechanism had to decide logically how best to act on the demand for service initiated when the customer lifted his receiver. Several equipment elements were designed to serve their function quickly for one call and then go on to serve another call without waiting for all other functions to be completed. These elements, used in common by many customers' lines or circuits, formed the basis of common control switching systems. These have now reached a degree of refinement which makes dialing from coast to coast a commonplace thing.

Although the principles of common control have been applied to a variety of switching systems, the most widespread use of these principles has been with crossbar systems. In these systems, co-ordinate arrays of relay contacts are operated as "crosspoints" to establish a talking path through the system and to connect various elements of common control equipment as needed. These systems are used for local central offices, for tandem offices which can interconnect a number of common control local offices, and for long-distance switching too. Common control switching systems have proved themselves to be versatile and adaptable in a wide variety of applications.

THE NATION AT YOUR FINGERTIPS

ALEXANDER GRAHAM BELL's bold prediction in 1878, only 2 years after he invented the telephone, that ". . . a man in one part of the country may communicate with another in a distant place . . ." came true nation-wide in 1915 with the inauguration of transcontinental telephone service. Many people in the telephone industry over the years have had the same faculty for practical dreaming. One of their dreams was for a fast, accurate, convenient service permitting the customer to call anywhere automatically by fingertip control. This dream became a reality in 1951 with the first offering of direct distance dialing service (DDD) in Englewood, N.J. DDD service is now widely used and is growing swiftly.

The time between the dreaming of the dream and its fulfillment was a busy one indeed. Plans had to be developed for the routing and switching of calls over both short and long distances; a plan had to be devised to give each telephone a unique number; automatic mechanisms had to be designed with the most advanced memory and logic capabilities, not only to speed calls toward their destination, but also to record and prepare the information needed for billing. What is being built up (and is now largely in being) may be likened to a super-computer, comprised of computer-type switching systems interconnected by millions of miles of crosstown and cross-country circuits. In computer terminology, each one of 67 million dial service telephones can be a source of input information. Each call is a separate and unique problem to be solved. An average of over 200 million such problems are solved every day, the super-computer doing its own programming for each problem from a set of very general instructions. Each request for service is handled rapidly and accurately. A record is made of who is served and when and for how long for automatic preparation of charges.

The individual computer-type switching systems exchange information in one of several machine languages. Input information can be converted, deleted, or added to; the system makes its own decisions as to what is needed and often selects the best course of action from several alternatives. Many systems are self-testing to a high degree, automatically recording their own troubles. There is no "down time," 24-hour service every day of the year being normal operation, even while additions and changes are made to provide for growth or to add new features. To make this possible, the closest nation-wide co-ordination of every phase is necessary to ensure that each part of the system is properly integrated into the whole.

The whole program, of course, could not be put into action all at once. It started with operators dialing calls beyond the local range, which substantially reduced the time needed to set up long-distance calls. But this was only the beginning of a gigantic dialing program. As Englewood, in 1951 and then other exchanges have been engineered and equipped for customer DDD, the attractions of long-distance dialing have been rapidly extended to telephone users in many parts of the country. It is only a matter of time, and not very long at that, before most cities and towns will have DDD service.

There are, to be sure, many risks in embarking on such a long-term, forward-looking project. Such programs can only be undertaken by a financially healthy industry. It was necessary to commit huge sums of money for large-scale research and development, and to manufacture and install vast quantities of new telephone equipment and tens of thousands of circuits—cross-town and cross-country. All this forward-looking planning and execution of the DDD program has been vindicated by enthusiastic public acceptance of the service.

Work on improving the speed and convenience of telephone switching never stops. Direct dialing to P.B.X. extensions has been initiated commercially. With this service, a customer in the same or distant city can dial a particular telephone out of the many that may be used by a large business organization. The central office equipment makes an automatic connection to the desired telephone much faster than an oral request for an extension number can be completed.

Another big step toward fully automatic telephone service is now being tested. This test, and it appears to be successful, is an effort to speed up service further by letting the customer dial his own person-to-person calls. The assistance of an operator is needed only to see that the right party is obtained at the distant telephone and to signal the automatic recording equipment that conversation has started.

Today's telephone user, with the nation at his finger-

tips, finds his telephone service more accurate, speedier, and much more convenient than that of a generation ago.

MANY OTHER SERVICES

THE PRIMARY SERVICE which the telephone industry has for sale is, of course, telephone communication. In providing this service, vast quantities of communication channels must be designed and built. These channels also lend themselves to the transmission of a variety of other forms of communication—teletypewriter, pictures, facsimile, data for computers, control signals—whatever will meet the particular needs of industrial, financial, or transportation enterprises as well as the civilian and military agencies of the Government.

Still other communication channels make up the networks used by radio and television broadcasters. In addition, closed-circuit television services are often used for sporting events and business meetings. Twenty-five years ago, television networks did not exist. As of today, the telephone companies have 83,000 miles of video channels which carry programs used by more than 600 television stations. These channels represent an investment of $235 million.

Expansion of overseas service, both by radiotelephone and transoceanic telephone cables, now allows a customer to call any of 97% of the world's 125 million telephones. The connection of land lines with radio channels to ships in coastal and inland waters, inaugurated in 1935, now provides telephone service to more than 30,000 vessels. Mobile radio service, that is, radiotelephone connection of cars and trucks to land lines, grew from a few public-utility emergency vehicles in 1940 to many thousands of cars and trucks in all major American cities and on the highways too.

Emergency telephone system enables person placing alarm to talk directly with fire or police department.

Switching of television network programs requires co-ordination of people in many different cities. Craftsman is making a split-second circuit rearrangement.

OPENING DOORS TO TOMORROW

THE RECORD of the past is impressive any way you look at it. Those giant steps, however, were largely accomplished by the exploitation of research efforts made prior to World War II. In the postwar period, research and development efforts were accelerated as a consequence of the exciting advances in electronics spurred on by the necessities of World War II and the need to replenish our storehouse of basic knowledge. Perhaps the most familiar product of this accelerated research was the transistor, invented in 1948 at the Bell Telephone Laboratories, and its kindred solid-state devices. By 1953, the transistor was in service in telephone plant as part of switching system memory and logic equipment. Since then, its usefulness has been extended to other equipment and systems.

The advent of the transistor and solid-state technology, while a remarkable advance in itself, will not revolutionize telephone plant overnight. Rather, solid-state technology is another giant step forward in the evolution of the art of communication. New instrumentalities must be worked into new equipment design which will function in complete compatibility with billions of dollars worth of earlier instrumentalities.

As older equipment wears out or becomes obsolete, replacement will be made with the most modern equipment. Where growth in demand for service requires more equipment capacity, such as a new central office or circuit route, the most up-to-date equipment will be installed. In the meantime, older equipment will be updated by incorporating some of the new techniques. This evolving nature of telephone plant presents many problems to the design engineer, because he cannot start off with a clean slate. At the same time, it is an unparalleled opportunity for the exercise of creativeness and ingenuity.

This need for creativeness and ingenuity extends not only to research and development, but also to all areas of activity in providing communications services. To furnish only the best in service, the telephone industry must continuously seek out those areas in communications where there are opportunities for innovation and improvement while avoiding change for its own sake. In a nation of expanding population and rising living standards, one must think and plan dynamically for a generation ahead. New arts must be introduced with a flexibility that will allow still newer arts to add their contribution when the time is ripe. There is no place in the scheme of things for complacency or self-satisfaction. As was mentioned at the outset, "There always is a better way"– and this applies to methods of operation as well as to plant facilities.

Pocket radio signaling service gives audible signal in receiver being carried by person using this service which means "Please phone in." Radio signal is sent from telephone office when someone asks to have customer signaled.

THE CUSTOMER RULES

THE PRODUCT of the telephone industry is service—a personal service. A connection between the customer's telephone and any other must be made to his personal order and for his exclusive use for as long as he wants. With fast convenient direct distance dialing making the assistance of an operator necessary only now and then, how to keep an impersonal note from creeping into the service becomes a very real problem. However, the new art based on devices of solid-state physics will open the door to many personalized services. We have only an inkling of some of these; others are just around the corner.

A new service, recently introduced, in effect provides an extension bell for a salesman, a doctor, or anyone away from home base. This is done with a small, light, pocket-sized radio receiver which gives an individual signal to the customer that his home or office would like him to telephone in.

Many imaginative stories of the future have taken for granted that visual communication between two persons will be as commonplace as television entertainment is today. No doubt the day will come. The know-how has been achieved. What remains is imaginative development effort to bring the cost of such a service within the means of many people and marketing and promotional effort to find uses for it.

The future trend in telephone instruments will most likely be toward telephones with pushbuttons instead of dials, and tone signals much more pleasing to the ear than the present bell signal. The ultimate of this trend would be the complete elimination of a visible telephone instrument. Concealed microphones and loudspeakers in the home or office of the future would allow the customer complete freedom of movement, much like that enjoyed by the people interviewed on a current television program. Frequently called telephone numbers would be dialed automatically from preset information.

Another aspect of service which will receive more and more attention is the expansion of local calling as the day-to-day communication needs of customers expand beyond their own immediate communities. This need has already been met in many areas by giving extended area service (EAS). This means that calls to nearby communities, instead of being charged for individually, are treated as local calls and are usually covered by the basic monthly rate. As the calling patterns change, EAS can be made wider and wider in scope if the public wishes. There are no significant technical limitations to encompassing large areas—even to the point of providing state-wide or nation-wide calling. The matter hinges on the public's desires and the economics of the situation. With new carrier systems—cable, radio relay, waveguide—distance becomes a smaller factor in costs.

AS NEAR AS YOUR TELEPHONE

THE EQUIVALENT of face-to-face conversation has be-

come the goal of future circuit design—to bring anyone as near as the telephone.

Over the past 25 years, not only have new facilities steadily improved in faithful transmission of the human voice but, by means of carrier techniques, circuits have come in bigger and bigger bundles to furnish the huge quantities needed for today's fast service. These advances came from two key tools: one was a device—the vacuum tube; the other was a principle—the theory of modulation.

Forecasts for future needs for circuits are tremendous. But fortunately, two new keys are in our hands to open another door to the future. These are, as before, a device—the transistor and its cousins, and a principle—information theory. With the transistor, both space and power requirements are drastically reduced. With information theory, the telephone engineer now has a mathematical tool with which he can analyze the potentialities of communications systems. Work in this field has focused attention on the problem of the redundancy inherent in most communications sources. A great deal of the repetitious content is not essential to the faithful transmission and comprehension of a message. Any reduction that can be effected in redundancy makes the use of a communications channel more efficient.

In investigating different methods of transmitting messages, quite a bit of consideration has been given to a sampling technique with which a brief look is taken at one message—for a time measured in microseconds; then a similarly brief look is taken at a second message, a third message, and so on. Only a series of samples need be sent over the circuit. At the far end, these samples are reconstructed into the original messages and no one notices that parts of one message were never transmitted while other messages were being sampled. Having the message in this sampled form, one way to gain freedom from noise and distortion in transmission, is by coding the samples into binary pulses. This process, called pulse code modulation, or PCM, offers great possibilities for transmission over media having high attenuation, noise, and distortion since the pulses can be perfectly regenerated at repeater points along the way.

Pulse code modulation seems certain to find its place in the design of future transmission systems, but as a competitor—not as a wholesale replacement—for the old work horse, frequency division carrier. It now appears that the regenerative capability of pulse-code modulation is an important key to the simultaneous transmission of hundreds of thousands of telephone conversations or hundreds of television pictures through waveguides in the form of copper pipes—literally cross-country communications pipelines. Such waveguide systems, which will operate at frequencies in the order of 50 billion cycles, are in early stages of development. Surely they will be an important factor in meeting the communications needs of the next quarter century.

In short-distance applications, particularly within metropolitan areas, there will be increasing use of carrier on the thousands of miles of cable pairs in ducts beneath city streets which now furnish only one circuit per pair. And here in many cases, pulse-code modulation may make possible the economical equipment needed to prove in the carrier application.

Looking into the future, a need is expected to develop for transoceanic communication far beyond that of today. One of the major problems is to increase bandwidth to provide enough channels for all kinds of communications channels—voice, data, television, etc. The ocean telephone cables to Great Britain and Alaska placed in service in 1956, and since then to Hawaii and very soon to Puerto Rico and France, provide 144 kc of bandwidth—enough for 36 high-grade telephone channels. Development is nearing completion on an ocean cable that will provide 1,000 kc of bandwidth—sufficient for more than 100 two-way telephone channels in a single cable. Preliminary work already under way may lead to even more bandwidth through cables employing transistor amplifiers—perhaps enough to permit transoceanic television networks.

Another way to enlarge telephone channel capacity is to use available time more effectively. On a channel used exclusively for a single conversation, speech is transmitted for only a fraction of the time in each direction. There may be a wait to get the distant party on the line; both parties frequently pause between words and sentences; each stops talking to listen to the other party. Telephone engineers have discovered a way to automatically interleave other conversations during these periods of silence on a time-sharing basis by pooling a number of telephone channels. Through this means, the present 36 transoceanic telephone channels could carry about twice as many simultaneous conversations. Design of the equipment to do this, called TASI (Time Assignment Speech Interpolation) is now under way.

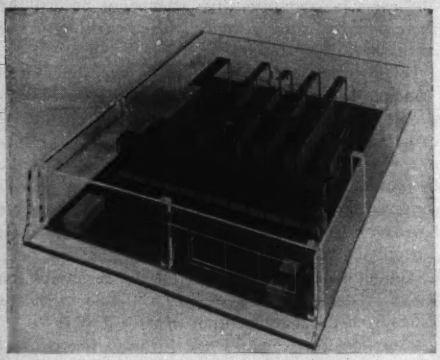
A CHIP OFF A NEW BLOCK

IN ITS VIGOROUS POSTWAR GROWTH, the art of communications has fathered many new concepts and devices. One of these healthy youngsters, not yet quite ready to set out on its own, is electronic switching. The enormous advances in electronics, and the advent of the transistor with its allied "new art" devices, will make possible two essential changes in switching systems. First, an ultrahigh-speed operation, measured in microseconds, will allow a single unit of common control equipment to serve an entire central office. Second, there is the fantastic capacity for memory and logic capabilities. The ease and speed with which new or changed instructions can be written into, or erased from, electronic memory will make possible services tailor-made to suit the needs of each customer. For example, it will be feasible to:

> Automatically set up connections to a frequently called telephone number when the customer dials a single digit. Electronic memory will associate the customer's line with the digit dialed and thereby

"know" that it is to ring a particular distant telephone.

Automatically dial a series of calls in sequence when the customer dials one or two digits. Again, electronic memory will "know" exactly what to do from its instructions.



Plastic model shows proposed layout of 4,500 line electronic central office. First experimental electronic central office is scheduled for installation at Morris, Ill., in 1960.

Automatically redial a telephone number which was busy on the first try but is now free; the equipment remembers the telephone number called and the line of the customer who made the call.

Automatically set up a conference network within a business headquarters building, a branch office, or even at widely scattered offices. All of the extension and telephone numbers desired will be stored in the electronic memory. The customer need only dial the appropriate code to order this service.

Automatically transfer a call to some other telephone number. If a customer leaves his home or office for a short time, he can arrange temporarily to have his incoming calls transferred to another telephone where he might be reached. To do this he dials an appropriate code and the other telephone number. The electronic memory will then do the rest.

Permit much faster establishment of communication service or changes in service by simply placing the needed information in the memory rather than making wiring changes.

Provide flat-rate calling areas tailored to the needs of the individual customer, with information as to charging arrangements for individual cases stored in the memory.

These and other services not yet envisioned will be possible as the potential for extremely compact high-capacity memory and logic instrumentalities is transformed into reality.

Small size and low power requirements not only will provide new services but also will lead to more economical use of materials in telephone plants. For example, nowadays each telephone must have the use of a pair of wires all the way to the central office even though there may be only an hour or two of actual use per day. If some of the concentrating functions of the central office could be placed nearer to the telephone served, much copper could be saved by using fewer but harder working cable pairs between the concentrator and the central office. Such remote concentrators now appear to be feasible.

It will not be necessary to wait for older equipment to be replaced with new systems in order to offer many of the new services which electronic switching affords. The adaptability of the transistor and its allied new art devices to all kinds of circuitry will make it possible to keep older types of switching systems up-to-the-minute—a kind of wedding of the old and the new. Modification and conversion equipment—"black boxes," if you will—using the newest electronic arts, will enlarge the memory and logic skills of older switching systems as the new and wider services enumerated earlier are introduced. Development work is under way on more proficient memory and logic equipment to make today's switching systems more versatile in their basic function of connecting any two telephones.

The introduction of electronic technology has presented the communication services engineer with a real challenge. In the telephone industry, as in other industries, not only must the technological problems of progress be solved, but the practice of sound economics is all-important. For in the final analysis, communications services must be economically attractive to the customers and to the industry. Achieving this balance is a big job and a continuing job. It requires the skillful blending of today's instrumentalities and tomorrow's new technology and devices. Only in this way can the fast, comprehensive, and economical communication service be provided which the customer of tomorrow will come to expect.

IT'S A SMALL WORLD

THE CERTIFICATE of incorporation of the American Telephone & Telegraph Company, filed in 1885, declared the intention of interconnecting all cities, towns, and places coast-to-coast, to Mexico, to Canada and to "the rest of the known world." With several thousand Independent Telephone Companies joining hands with the Bell System and by agreements with most of the countries of the world, this goal of world-wide communication has been attained. But this is surely not the finale in the art of communication. For in a world of change, new things are always on the horizon. Thus, "a nation at your fingertips" will become "the world at your fingertips"; in two words: universal dialing.

As happened with nation-wide DDD, a period of planning and implementation, now just starting, is necessary. Plans for automatic routing and switching, exchange of supervisory signals, and standardization of

Service for air travelers at present is being furnished on experimental basis between Detroit, Mich., and Chicago, Ill. Passengers on planes equipped with service may be connected with any telephone in nation-wide network. Eventually, it is hoped that air-to-ground telephone service will be available along all major air corridors in United States.

transmission levels must all be worked out. Differences in alphabets and dial designs need to be reconciled. Inasmuch as numbers are more of a universal language than alphabets, some consideration is being given to the use of only numerals for telephone numbers. No doubt the problems to be surmounted in order to achieve universal dialing will be great. But a start has been made. Customer acceptance of DDD has been enthusiastic. Purposeful and imaginative service-minded engineering will continue to attain new goals, if only they are set high enough.

FUTURE UNLIMITED

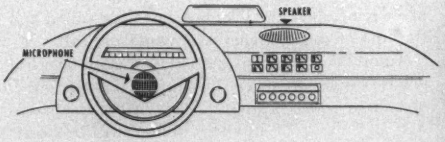
REAL AGE is not measured in years but in youthfulness of outlook. As the telephone industry goes about its business over the years, its alertness and enthusiasm for new ideas, new devices, and new services will give impetus to a growing variety of communication services for a growing nation.

America is on the move as never before in its history. In his desire to get going, the customer takes his inclination to talk right along with him. It is now possible to talk to anyone by telephoning while riding in almost any form of transportation. As mobile service is made more convenient and useful, many more people will want it. It is not straining the imagination too much to think of a pushbutton hands-free telephone as a standard automobile accessory.

The glamour and usefulness of electronic computers are too well known to need any discussion here. The wide use of computers does, however, require that a new dimension be added to communication services. These machines speak a language of pulses and it will often be necessary for them to talk to each other: for instance, for centralized inventory records, for centralized transportation reservation service, for centralized billing information processing, and for many other time- and money-saving practices made possible by automation and integrated data processing. The whole family of computers and other machines which process data may sometimes talk directly to each other, as when an immediate reply is needed for transportation reservations, or may talk through the medium of punched tapes, magnetic tapes, or punched cards. In any event, a communication channel is needed. And there may be many occasions when switching arrangements are also necessary.

For the telephone industry, there is no difference in principle between setting up a connection over which people can talk or over which machines can talk. In each instance, a device is needed to convert the input to a type of signal which can be transmitted and then be restored to its original form at the distant end. For conversation, telephone subsets are used. For machine language, dataphone subsets will be needed. Just as a telephone can be used for speech in any language, a dataphone subset will be used for the variety of computers or data-processing devices available to the customer from the manufacturers of such devices.

Dataphone service will work this way: The customer will use his regular telephone to call the location to which he wants to send data. He will tell the distant party that data is to be sent and then both will switch their dataphone subsets on to the connection over



Possible future mobile telephone installation is depicted. Hands-free operation and push-button dialing will undoubtedly be incorporated and the speaker, amplifiers, etc., of the car radio will be used jointly for the telephone receiver. Where high noise precludes hands-free operation or where privacy is desired, a hand set will be provided.

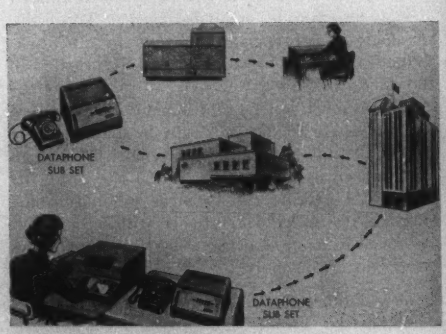
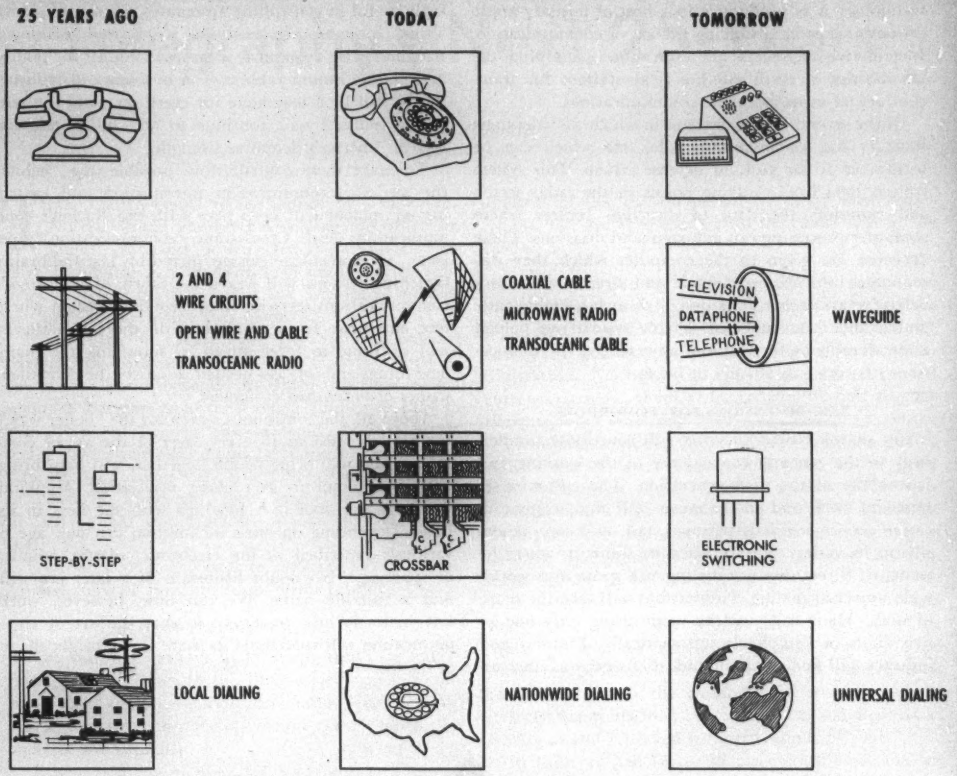


Diagram illustrates how telephone facilities are used to tie together two data-transmitting and receiving sets. Dataphone subset adapts communication channel to data transmission.



The art of communications has come a long way in the past 25 years. The future holds great promise for even greater advances.

which they have been talking. The dataphone subset will convert the data into the form required for line transmission. At the far end, another dataphone subset will restore the signals to their original form for direct connection to standard business machines, teletypewriters, or recording equipment of the punched card, punched paper tape, or magnetic tape varieties.

The ultimate requirements for data are not yet visualized, but computers can be very fast talkers indeed. Looking to the future, wide-band circuits may be needed to accommodate the deluge of data which business, industry, and Government will originate in some applications. The potential applications for data transmission seem almost unlimited and the extent of such communications may some day rival the volume of basic telephone traffic. There appears to be much merit in handling voice communication and data jointly over one big telephone network, sharing the same switching systems and transmission facilities. Even channels of different capabilities, such as narrow band or extra-wide band, could be pooled and the right type would be automatically selected by the switching systems.

And, of course, as soon as the problems of data transmission are solved—or even before—there will be needs for even newer services, probably some undreamed of today.

COMMUNICATION IS VITAL TO DEFENSE

Modern electronics and solid-state device technology have ushered in the age of pushbutton control of military operations, making reliable communications increasingly important. To provide such reliability, the telephone industry's efforts encompass decentralization of switching at major centers, diversification of cross-country backbone routes, addition of routes which bypass probable target areas, and revision of operating practices to ensure that priority calls go through promptly.

With its unique know-how in the realm of communication arts, the telephone industry is making many valuable contributions to all areas of the defensive effort, including warning systems, alerting systems, and systems which direct defensive operations. Also, of course, the industry's wide experience in research and

technology is as productive in a host of military applications as it is in advancing the art of communication. Imaginative engineers are even now examining the possibilities of earth satellite relay stations for transcontinental or transoceanic communications.

Of the several defense systems in which the telephone industry has an important role, one which can be mentioned is the SAGE air defense system. This system collects data from outlying points in the radar screen and transmits the data to direction centers where computer processing can aid command decisions. These decisions are given to the computer which then disseminates information to guide and direct the Nation's defensive armament. The design of such a highly integrated and interconnected defense system was helped immeasurably by the fact that an extensive communications network was already in being.

NEW DIMENSIONS FOR TOMORROW

THE ART OF COMMUNICATION will contribute wonderfully to the zest and convenience of the working and leisure life of the next generation. The customer—at home, at work, and on the move—will enjoy communication service which is personal, fast, and comprehensive in its variety. Service when he wants it, where he wants it. Direct distance dialing will grow into worldwide universal dialing. Pushbuttons will take the place of dials. Many calls will be made using only one or two digits or completely automatically. Business and industry will find the communications network increasingly useful in controlling automated offices and plants. Visual communication will be widespread, making a telephone visit even more pleasurable for all the family, and finding innumerable uses in business and industry. There will be a telephone for every car. And the telephone industry will continue to add in an essential way to America's defensive strength.

To make these contributions possible, the "behind the scenes" communication transmission and switching equipment will keep pace with the Nation's communications needs. Cross-country communication "pipelines," transoceanic television, incredibly fast and brainy switching systems will weave the fabric of tomorrow's communications services. In an economic system where free enterprise is encouraged to do the job, industry will continue to forge ahead in supplying the many new things and services needed to satisfy the diversified wishes of *individual* customers.

Above all, the continuous search for the "better way," for new dimensions in every facet of the art of communication will bring people together, will help bring nations together in ever closer association. Mankind stands at the door to a new age with the keys in its hand. Depending on one's inclination, this new age is variously described as the electronic, plastic, atomic, or space age. No doubt historians of a later era will find a suitable name. We can now, however, work imaginatively and creatively so that the art of communication will contribute its share to the bright shape of the future.

Telegraphy's Next 25 Years

I. S. COGGESHALL
FELLOW AIEE

THE TOPIC comes to the author by assignment. No one would volunteer a writing for which he might reasonably be expected to be pilloried in effigy in 1984 as part of AIEE's celebration of its centennial. It will be shown that any attempt to predict will prove futile before it is made.

In fulfilling his assignment, the author's obvious recourse was to treat AIEE's fourth quarter-century as an extrapolation beyond the third—the one which spanned the years from the Golden Jubilee of 1934 to The Diamond Jubilee now at hand. At first blush, seeing 1984 from 1959 might be found to be no more difficult than seeing 1959 from 1934. Hindsight there is plenty of. Hindsight, then, might be used as the propellant that would get us off our 1959 launching pad.

We tried it. We went back to 1934 and looked ahead. Immediately we ran into count-down trouble.

THE QUARTER-CENTURY BEHIND

THE MAN DID NOT LIVE in 1934 who could see today's developments. Refer to the illustrations which accompany this article. Clairvoyance would have muffed them. Imagination-run-riot would have fallen far short of the actuality.

Submarine Telephone Cables. True, in single instances the germination was imminent and might have been subject to short-range forecast by specialists in 1934. A transatlantic telephone cable was foreseen; *the* transoceanic cables, no. The first shallow-water submerged amplifier was destined to undergo initial development in England only 4 years later (1938) and be laid in the water in 1943. But a 1934 prediction to be worth anything would have had to foretell the picture of several completed 36-voice-band telephone cables laid in several oceans, some containing strings of half-a-hundred repeaters in series; the production of vacuum tubes which would not burn out and other circuit components whose characteristics would not vary when subjected to ocean-bottom pressures of tons to the square inch. A new dielectric, polyethylene, to replace gutta percha, would have had to be foretold, capable of standing up under electrical stresses manyfold greater than any heretofore experienced in ocean cable practice; the technique of riding and bucking the varying earth-currents prevalent in cables; the technology of broadband amplifier design, of the control of signal-noise ratios, and of coaxial cable transmission of high quality. These and many other developments of the 1935-50 period were not even hoped for in 1934, yet were essential to the cables laid in the 1950's.

High-Speed Binary Switching. If the posture of blindness is accurately descriptive of 1934 in relation to comparative low-frequency submarine telephone cables, it is doubly appropriate in relation to the other illustrations, for in all the apparatus depicted control currents circulate about at frequencies beyond all comprehension 25 years ago.

In the electronic revolution which took place during AIEE's third quarter-century, first place should probably be assigned to the linking together of the two-position switch with the binary system of computation. That, and the extension of the use of switching to perform operations in logic, were inspired developments hardly to be foreseen by anyone—certainly not as to their present universal application—25 years ago. For by the use of the vacuum tube as the switching diode and later the transistor, direct current was found to be reversible as a single function of time at rates reaching up into the millions per second; and by orderly manipulation, information so handled could be stored and retrieved in microseconds of time.

In 1934, we had Hollerith mechanical card-punches, card sorters, and totalizers, which later became fundamental building blocks of digital computers as we know them today. At that time, also, we had analog computers of reasonable complexity performing sophisticated calculations; but no aching void for digitals was making itself felt—in fact the analog appeared fully capable of handling tricky mathematical problems that an adding machine could not handle. Then, in 1945, Howard Aiken at Harvard University asked the telegraph company for teleprinters, reperforators, tape transmitters, and transmitter-distributors, to be wired up as the input for his *Mark II* digital computer. The machines which were readily available ambled along at the standard speed of 65 words a minute. We telegraph people were delighted to see the venerable telegraphic pulse going to work in new overalls. Now, in 1959, the flip-flops work in the megacycles and the printers print a line at a time instead of a letter at a time. In 1934, we were blind to the problems, blind to the solutions. Counting on two fingers instead of ten? Manganese-zinc ferrite brains? What do you mean?

Television, Radar, and the Higher Frequencies. In 1934, the rudiments of television existed. Zworykin's iconoscope of 1923, Jenkins' and Baird's demonstra-

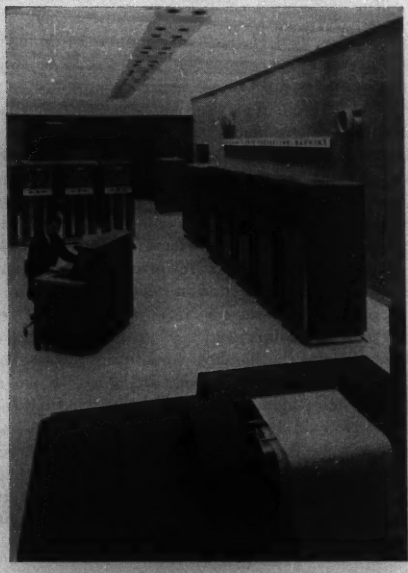
I. S. Coggeshall is assistant vice-president, Western Union Telegraph Company, New York, N. Y.

tions of the early 1920's, and Farnsworth's dissector tube of 1928 all pointed to the fact that television eventually would come. But how? Where was all the radio bandwidth to come from? The top of the spectrum was 30 mc—if one went higher, what would one do for tubes? If mechanical scanning were to be employed, what would be the nature of the light valve? The problems themselves were elusive; their solution encountered road-blocks at every turn.

World War II became a most powerful stimulant to technical progress. Radar was virtually forced into acceptance. Mastery of its principles brought powerful new tubes and pulse techniques. It opened the band of very-high frequencies (vhf), hitherto closed. Ultra-high frequencies (uhf) fell next, and before the war was over, super-high frequencies (shf), or microwaves, were put to work. The broad bands thus opened to modulation cleared the way for commercial television. In the wake of television came researches on solid-state crystals, ceramic dielectrics, and other basic materials and concepts. The technical avalanche gathered force, until today we have the experimental and working models depicted in our illustrations.

Government as a Major User of Facilities. No one would have guessed in 1934 the extent to which Government demands for telegraphic facilities would have risen by the end of a war that would far outdo World War I, nor have judged that the unprecedented level of demand could possibly be sustained by the national wealth for 15 years afterward. That kind of money was not being spent in 1934—a year of financial depression. To illustrate: the U.S. Navy in 1934 leased but one landline circuit—a Morse duplex between Washington, D. C., and Boston, Mass., with drops en route. No voice leases, mind you. The Signal Corps had no landline leases. There was no Air Force, as such. Now, teleprinters had been in widespread commercial use in the United States since before World War I, yet the armed services had none. This is not to imply that the U.S. Army and Navy were without telegraphs. They had comprehensive radio installations in 1934 and long before—they had pioneered in radio. But for lack of appropriations, in 1934 they could not keep abreast of the commercial carriers in assimilating and using equipment then modern.

Burroughs 3,000 wpm teleprinter. Letters are formed electrostatically in 5 × 7 dot matrices, 72 on each line, a line at a time.



In foreground is an International Business Machines read-out printer operating at 18,000 characters per minute as output of type 705 computer.

Then in succession came Hitler, the United States' preparedness program, Mussolini, Hirohito, Korea, and the Cold War. Billions were poured into electrical communication, including substantial amounts into radio and wire telegraphy and their techniques. Today "the shoe is on the other foot." Circuits of the most advanced types, supporting the armed services and a number of other governmental activities, are applied to the whole globe in a vast overlay. The most elaborate of all private wire systems are leased by the Government, comprehending electronically switched and error-protected teleprinters, data-handling systems between domestic and foreign points by radio and cable, extensive facsimile systems—everything "last word" and "biggest," as befits the job to be done.

A collateral result emerged as a central surprise element of the period 1939-59—one to which industry was

quite oblivious at the outset: the emergence of the National Government as principal catalyst of technical progress, a position it holds today. Not only in size but in content, private laboratories and the universities undertake for the Government the most advanced research and development projects. Today the telecommunication carriers would be happy indeed if commerce and business could support on a nation-wide scale the gilt-edged facilities and equipment that compose the Government networks. This reversal was certainly unforeseeable in 1934.

THE QUARTER-CENTURY AHEAD

MORE SO PERHAPS NOW than at other times predictions ought to be "hedged," out of deference to the uneasy possibilities of war of different degrees of intensity. Communication people by now have become well briefed on the devastation which would be caused by widespread use in any war of the full arsenal of atomic weapons. Government officials and lawmakers are as fully aware. Their direction of war communication preparations, both as to number of circuits in being or reserved and as to stimulation of communication research during the next quarter-century must, whether we like it or not, look to the hydrogen bomb as the decisive influence.

Statistically, the United States should become involved in war within the next 25-year period. The author assumes, therefore—realizing that in this sphere an assumption is bound to be construed as a prediction—that there will be a minor war, calling forth extra technological effort as was the case in the war between the Koreas. With due deference to the United Nations, this is a concession he makes to the fact that major wars have occurred in each of the previous three 25-year periods since AIEE was founded in 1884. The author further assumes that the United States, the other western powers, and their adversaries will not unleash, within the next 25 years, a war which involves general use of the most powerful atomic weapons. Under an assumption that there were to be an all-out nuclear-fusion war, this essay would not only be academic but fatuous, and the author is not prepared to admit the latter. Nevertheless, his clear conclusion binds nobody but himself and will do nothing to allay constant apprehension of total war and partial extinction for another two decades and a half.

Stromberg-Carlson 85,000 characters-per-minute teleprinter, utilizing Charactron read-out tube and Haloid xerographic printer.

Communication "Blitz." Enormous sums have been expended during the cold war of the past dozen years upon defensive installations like early-warning radar networks and ground-environment systems. Communication laboratories have been participants in their design. Telegraphic information services of this type will be modernized and expanded during coming years. With two powerful nations poised in military stalemate, and with their missiles and aircraft in readiness but under an uneasy restraint dictated by a lively appreciation of the disastrous effects of attack, retaliation, local destruction, and global radiological havoc, the instant availability of intelligence of opposing threats and movements is of utmost import. Hence, instant and complex telegraphic information-gathering capabilities, on a scale befitting World War III, will play a vital role in defense throughout most of the coming 25-year period.

There will be further refinements and modernization of automatic trajectory-sensing and gun-pointing or missile-launching military equipment, with increased information-handling capabilities and wider geographical deployment and co-ordination. This follows from the fact that the development of intercontinental ballistic missiles, with their support elements of telemetry, will continue to occupy a prominent position in the military arsenal.

Government Support of Research and Education. It has already been pointed out that by no means were all the developments technological that proved to be of most significance to electrical communication between 1934 and 1959, nor will they be during the next 25 years. A top position must be assigned to the extent to which the needs of Government shall determine the direction and level of activity in the telegraph industry's laboratories and shops.

During the years before us higher education will also continue to receive Government support through research contracts, thus permitting the expansion of laboratory facilities beyond a point which would be economic if confined to faculty- and consultant-induced research work alone. In reflex, industry stands to benefit from the better educational preparation of the grad-

uates whom it will hire, and from higher education's valuable contributions to the scientific press.

Volume of Government Communication. Apart even from its military arm, the Government, since 1941, has been one of the largest users of domestic and international telegraph communication facilities of all kinds. In 1959, it may be singled out as the largest contributing unit to telecommunication revenues. The record of the whole of the past quarter-century, from the first administration of F. D. Roosevelt in 1933 down through President Eisenhower, indicates a marked increase in rate of growth of Government personnel and appropriations year by year; as well as general acceptance, by both political parties, of the precept that only the Government is big enough to finance certain forms of business endeavor. While these trends have been deplored by experts, they have not been reversed in the give and take of practical politics. The pattern for the future may be assumed to have been set, with perpetually increasing Government activity as a source of income for the privately owned communication industry.

Regulation and Consolidations. The Communications Act of 1934 is just 25 years old. On the basis that a parallelism exists with the Interstate Commerce Commission (ICC), it is safe to predict that the Federal Communications Commission (FCC) will still be functioning in 1984. By then, the Congress may have been convinced that the privately owned telecommunication industry can render a better service, with proper public safeguards, under regulation than under wasteful competition. In any event its attitude will have become more liberal in permitting mergers which take into account the essential physical unities existing among: (1) telegraph and telephone, (2) wire and radio, and (3) domestic and international operations. The executive department and more agencies than exist today will be administering revised laws accordingly. Telegraph service will be better and more efficient. It will not be cheaper because of the circumstance that long-term inflationary money trends will have masked the lowering of real costs and prices.

Distinctions between Forms of Telecommunication. A feature of the past quarter-century has been the manner in which boundaries have been erased between wire and radio as means of transmission, and among the telegraph, telephone, television, and radar forms of technology. This has been most marked in Europe, where all come under a common administration, for the most part. Even in the United States where the various modes are dispersed, the facts of life have had to be acknowledged. In 1934, there was no one to prophesy that within a few years most intercity trunk telegraph circuits would be shifted from railroad rights of way to telephone–telegraph carrier; nor that, between 1950 and 1958 almost a third of the Nation's long-distance circuits would be shifted from wires and multi-pair cables to microwave radio. Telephonic transmission by periodic sampling and phase-shifting of pulses thus sampled was an unknown art. Telegraphic transmission of nonlanguage signals, as a major growing sector of the business was not even embryonic.

In the coming 25-year period, practical elimination of the remaining distinctions will have taken place. Encoded signals will be handled in "quanta of gray" as well as in black and white. Conversely, telephony will utilize pulse modulation methods that do not involve linear relationships of amplitude variations with sound-source intensities. In addition, there will be a leveling off of the remaining distinctions between the arts of wire and radio transmission, already apparent in 1959 in overseas telephony and in network television and sound broadcasting.

Competition between Communication and Transportation. Competition will be intensified between the delivery of information by physical transport and by electric transfer, as speeds of aircraft and other airborne transportation devices are developed—so much so that the capabilities of planes to transport motion-picture film, television tape, blueprints, and so on, will bear directly upon the feasibility of establishing telecommunication circuits, like television and facsimile, in specific locations and applications.

Public Telegram Service. The bread-and-butter public service of the telegraph company, rendered by means of branch offices, messengers, and telephone pick-up and delivery, will follow recent asymptotic trends, and will yield to direct customer interconnection wherever volume traffic is concerned. Few tele-

RCA Ultrafax receiving terminal showing clock which timed the transmission, in 2 minutes 21 seconds, of 1,047-page novel, "Gone with the Wind."

grams will undergo more than one keyboard manipulation before delivery, and in most cases that one will take place on the filing customer's premises. Whether there will be storage en route will depend upon the outcome of the teetering balance between the cost of line channels and the cost of electronic storage and alternate-route switching in repeater and terminal equipment, with the odds in favor of the elimination of most storage. Storage, after a few years, will be in electromagnetic or electrostatic, rather than in punched-tape, memories. Line switching, during most of the 25-year interval, will be by electromechanical relays, as at present.

Time-division multiplex, or a still more efficient spectrum divider, will replace the start–stop, frequency-division carrier system now prevalent. Whatever the system, it must of necessity have to be self-synchronizing, self-phasing, and self-restoring after line interruptions—hence, completely adaptable to end-on-end section patching.

Voice-Band Spectrum Utilization. Voice-frequency bands assigned to telegraphic (inclusive of data) communication will be more tightly stacked and more tightly packed than at present. Portions of bands heretofore allotted to the guarding of frequency-divided telegraph channels, from interference from adjacent channels, will be filled in. Useful purposes and means of retrieval will be found for the idle direction on half-duplex setups, now held in reserve for purposes of break-in and responses. Time now required for the transmission of the start–stop loading on teleprinter intelligence will be salvaged. The totality of the capacity of voice-bands (or subbands, or groups of voice-bands) will be apportioned among minute-to-minute applicants for service, not in standard 60-speed, 5-unit channels as at present, but packaged to suit each applicant's momentary requirement of (a) total number of pulses per minute and (b) the number of pulses (such as 5, 6, 7, 8 . . . *n*) in each character. The processes used will begin with those now foreseeable: magnetic memory matrices, electronic counters occasionally synchronized, or varieties of sweep circuits used in television.

Terminal Handlings. The electrical connection of filers of telegrams with central telegraph offices will have reached the practical saturation point within the first half of the period under discussion. Otherwise, problems connected with local pick-up and delivery will be present and no closer to solution in 1984 than in 1959. The same terminal difficulties which beset the telegraph company will continue to impede the prompt delivery of air mail, rocket mail, and any other kind of dispatch which cannot be delivered by electricity into the home or place of business.

Teleprinter Exchange Services. Telex in Europe, TWX and telex in the United States and Canada, and transoceanic telex (or tex) will continue to grow rapidly for several years before tapering off. Automatic switching will find preference over manual; keyboard, or director, switching over dial; and relay over electronic switching until such time as advanced spectrum-packing systems (mentioned previously under voice-band spectrum utilization) become standard. Concurrently with the adoption of devices for full band occupancy, electronic director switching will be introduced on a wide scale.

Director vs Dial Switching. The use of the dial for establishing through circuits already shows signs of being too slow and cumbersome for the switching of the future, and does not lend itself so readily to repeating and storage with language and data intelligence as does some form of director switching. The prediction is ventured that director switching will continue to be preferred in private telegraph network operations and will gradually replace manual switching and dials in teleprinter exchange and national public telegram networks. There will be exceptions in small countries.

Gentex vs Reperforator Storage. Gentex, the European system of switched direct interconnection of originating and delivering telegraph offices for the unit handling of each separate telegram, will prove uneconomical as to trunk utilization for public telegram services in geographically grand countries. The use of gentex will grow in smaller communities. The disparity between costs of furnishing leased wire and unit telegram services, already great, will be magnified as time goes on. There will therefore be continued pressure put upon efficiency and all possible economies in the basic and well-patronized public message service.

Teleprinter Speeds. Keyboard dexterity has been pretty well tested out in industry and office practice in the past 50 years. Since 1934 (and before that date), no disposition has become apparent to set higher standards of keyboard output. Except to the extent that electric typewriters become more prevalent and contribute to the ease of keyboard manipulation, typing speeds are not likely to increase much. In the spurts, typists commonly attain rates around 110 words per minute but they do not sustain them long. The present 65 wpm multiplexes fairly well dispose of the on-line output of such typists, but 60-speed start–stop arythmic keyboards do not. Considering the growing unification of electric typewriters with telegraph transmission, an estimate of the situation in 1984 is to the effect that 75 wpm on-line speeds will be more typical that 60 wpm, but that on-line operation will be less common than in 1959. Off-line preparation of signals will be by an applique to the electric typewriter. Punched holes in tape will have been superseded by a quieter means of storage—probably magnetic or electrostatic, of the type which will be evolved for the processing and transmission of other business office data. The run-off speeds of such data will be such as to occupy the entire voice band (as we know it to-

Exploded view of first deep-sea cable amplifier, laid by Western Union in 1950, with vacuum tubes powered from shore over telegraph cable.

day) but of a protected-pulse type which all telegraph companies will offer before 1984.

Facsimile vs Teleprinters. No one would have foreseen in 1934 that by 1959 the telegraph company would have installed in business offices more facsimile machines than teleprinters for handling telegrams. Up until now, however, facsimile has not been used on the main trunks for telegrams, nor, except for weather maps, for any other wide usage. Telephotography is generally confined to news pictures, though adapted to transmission of printers' proofs and other uses.

As broadband telegraph facilities become cheap, the use of facsimile between and among the principal cities will grow. Switched private line facsimile systems will be established within the period under discussion, on the same basis as teleprinter exchanges, and will in part replace them. However, one system will not entirely replace the other before the end of the quarter-century, nor will facsimile and teleprinters be made compatible in a single system with automatic interchange accomplished by readers or translators.

Broadband Operation. Microwave beams, coaxial cables, and waveguides will set the pace for bandwidths measured in kilocycles and megacycles for telegraphic forms of modulation. In ocean cable technology, solid-state materials of the transistor type will reduce emf drops per repeater; and without undue strain on insulation will make it possible to accommodate television bandwidths on an intercontinental scale. Although there will be further successful attempts to exploit heterogeneities in the stratosphere, troposphere, and ionosphere, except for special applications these methods will yield to more stable means of communication. The same may be predicted for refraction from ionized meteor trails. However, during the next 25 years, enough artificial satellites will have been launched to provide reliable and constant communication, using them as passive reflectors. Solar-powered active repeaters will have entered into experimental use by the end of the period.

Overseas Radiotelegraphy. In the future, the high-frequency band of the radio spectrum will be more efficiently packed. This will be accomplished by means already referred to in the better utilization of each voice band, plus wider utilization of single sideband techniques, and assignment of frequencies en bloc for the better co-ordination of transmitters. More microwave and waveguide landlines, more overseas radio links of the forward-scatter type, will be worked together, end to end. Latin America will preoccupy more communication attention than hitherto. High-frequency (short wave) radiotelegraphy will find itself sharing loads with cables to a greater extent than in the recent past.

Language and Nonlanguage Information. Second only to Government, business will exert the pressures which will produce new forms of telegraphy, beginning in 1959. Business demands will take the form of a greater volume of information to be transmitted, at higher speeds, with greater accuracy, and at lower prices. The press will echo such requests and ask for additional concessions. These demands will be satisfied, at least in major part. A trend apparent in the recent past toward the offering, by business, of nonlanguage material for transmission will be more marked in the ensuing years. Such nonlanguage information will take two broad classifications: (1) the control of machines and batteries of machines in factories, associated by wire with central control offices; (2) direct and flexible couplings between business-machine units which are separated by distance, so contrived that after current data and stored data are consolidated, the computer will digest it and call attention to the items which have particular significance, subordinating the remainder.

Forms of Language Communication. Dispatches offered for transmission will take forms somewhat more complex than today's telegrams. There will be growing use of the business letter format as to size of paper, arrangement of text on the paper, and use of lower-case letters as well as upper-case. Some of these problems will be solved by facsimile. Demands will be felt for the coupling of communication facilities to electric typewriters, duplicators, and addressing machines. The use of multiple-address telegrams having a common text will increase.

Associated Techniques. Telegraphy will continue to draw heavily upon the resources of radio, telephony,

photography; magnetic storage, of the drum, tape, core, and other memory types; electrostatic storage, of the xerographic types; and the computer arts. It will also keep abreast of and accommodate itself to new developments in office machinery and processes.

Miniaturization and Modular Construction. Though known previously, the printed circuit first assumed importance in the proximity fuze of World War II, which contained certain compact elements of television in miniature. Combined with tiny units of resistance, capacitance, and inductance; with two-sided plastic board construction; with printed contact-clip mounts; later with tiny transistors and diodes—the printed-circuit inserted assembly has become a bellwether of future electronics gear. It has already gained a foothold in computer, telephone, and telegraph equipment assemblies. The next few years will see its general employment as one solution to the problems of the maintenance of complex circuitry.

Telegraphy in Space. Before the end of 1970 there will be telemeter reports sent from the surface of the moon under control of interrogation from the earth. During the next 25 years there will be more or less constant use of the moon as a passive reflector of radio waves between points on the earth's surface, but commercial use will be impeded by the moon's phases and the earth's horizons. There will be no public telegrams handled to an office on the moon, under filed tariffs, before June 1984. Men in space vehicles above the earth's atmosphere will communicate with the earth by radio-telephone by 1984.

Telegraphy in the Home. Facsimile will have entered some homes by 1984. Fifty years ago, in 1909, orders for groceries were taken at the door by the man (and a horse) who would later in the day deliver them. The system broke down under the strains of cost, but it was more economical of the housewife's time than the aisles and check-out stations of today's supermarkets. It might be ventured that women will stand the existing makeshift for another 25 years but that their commandeered husbands will not. Some kind of a telegraphic adjunct to the home telephone has to make its appearance which will make it possible to place an order rapidly with a merchant so that he can assemble a package for delivery or call pick-up. I choose facsimile because it's the only picture I can bring into focus at this writing. Telephoning orders is too slow and conducive to time-consuming pleasantries. Televised telephony would be no faster; it would further divert attention and would fail to leave a written record at point of receipt.

By some, it might be objected that this prophecy is retrograde in that it fails to recognize the socializing role of the supermarket. This criticism is valid. To meet it head on, I envision another addendum to the home telephone of 1984. It will have a "hold everything" button. The housewife presses it and rapidly dials six numbers, then presses a "ring" button. She encounters one "Don't Answer," one "Line Busy," one "Wrong Number," but she gets three other girls on a party setup and they have a real good time.

Miscellaneous Predictions. During the ensuing quarter-century, amateur and commercial telepathy will hold no threat to commercial electrical communication. Sir Oliver Lodge and Sir Arthur Conan Doyle will remain incommunicado for the next 25 years. During the whole of the period "there will always be an England" and an AT&T.

CONCLUSIONS

EXTRAPOLATION OF FIGURES of physical growth items measured in numbers of messages or dollars is readily performed by plotting with a straight-edge on logarithm paper, but had better not be carried beyond 10 years. Projection into the future of a cell-dividing, fermenting, seething, mushrooming, burgeoning process like scientific discovery and its engineering applications, does not plot on graphs.

It is said to require 10 to 15 years for today's idea to become tomorrow's accepted actuality. If this be so, 25 years ahead is too far to hope to look. The existence of a problem may not be recognized as such until 10 years hence, the solution of which will find hardware in use a quarter-century from now.

It may be concluded from this recital that, if 25-year predictions pertaining to an industry are necessary, the jubilee years of AIEE are years to avoid.

Ramac 305 can store 10 billion digits and is operated from console (right). IBM photo.

CENTURIES are remembered—not for the passage of time—but for the men, the events, the discoveries, and the innovations they produce.

Although only half spent, the 20th Century has made an impressive mark on each count. Most impressive of all is the progress that has been made in technological innovation.

Among these innovations, few have created greater excitement than that caused by the discovery and development of electronics. In the field of business machines, electronic innovation has led to the development of ultrahigh-speed computers for which new and more versatile uses are being discovered almost every day. Within the relatively few years that they have been a part of our technology, these machines have found application in practically every major form of human activity.

No one, as yet, can foretell the many effects these machines may have on our lives. But on one thing all are agreed—businessmen, scientists, and economists alike—electronic business machines, and especially computers, are already beginning to change profoundly the ways in which we work, the ways in which we search for new knowledge, and the ways in which we defend ourselves.

In terms of the future, the picture appears all the more exciting. Most observers are convinced that electronic business machines will continue to occupy a place of growing importance, not only in business, but in all other human affairs. Ultimately, some say, the changes which may come in the wake of these developments will prove more momentous than those which came out of the industrial revolution.

Of all the developments we have witnessed in this industry, none are likely to be more eventful than those which have come in large-scale data-processing systems. Few innovations have covered so much ground so fast. Few have percolated into so many areas of activity so quickly and in so many ways.

Data-processing systems—as the term is used—ordinarily consist of a combination of units, including input, storage, processing, and output devices. They are designed to handle business or scientific data at electronic speeds with self-checking accuracy. The key element of these systems is the processing unit, a high-speed large-scale electronic computer.

Like all forms of nuclear application, these electronic data processing systems represent a post-World War II innovation. It was not until after the war, when research sought further uses for wartime discoveries, that engineers learned how to substitute electronic devices for relays to produce the first electronic computer.

Within a period of two decades, we have progressed from experimental laboratory equipment to machines the capabilities of which are exceeded only by the range of applications to which they can be put.

Like atomic energy, these developments in data-processing equipment have commanded world-wide attention. Opportunities for application of the equipment appear almost without limit. With each new application, data-processing systems have demonstrated still newer ways in which they can be used to help man enlarge his capabilities and advance civilization a little further.

For these reasons—before examining the technological developments which have spurred evolution of these machines—we may find it desirable to start with a broader examination of the place they have found for themselves in human affairs.

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For if we are to comprehend the importance of these advances, we must first attempt to see what these machines may mean to us. In the opinion of some scholars, what we have here is not just one more new industry or innovation—but a giant step forward in man's utilization of science and knowledge as a means to progress.

As such claims go, this is a very big claim indeed. Let's begin by seeing what grounds there may be for it.

CHANGING ECONOMIC STRUCTURE

MACHINES ARE DEVISED by men to fulfill a function. This function can be stated as a purpose. In the case of data-processing machines, the purpose can be expressed simply: they offer man a means by which he can increase his productivity.

They do this in two ways. First, they enable man to increase his output per hour as well as the quality of his output. This is true whether it be in research, in production, in problem solving, or in the distribution of goods and services. Second, these machines increase productivity by fostering good organization and control, and by encouraging careful and intelligent planning.

Data-processing machines came into being primarily in order to meet the increasing needs of man for information under increasingly complex conditions. In so doing, they confirmed an economic theorem which states that the development of a new technology occurs only when there is a pressing demand from society for the benefits to be derived from its use—and only when institutions within an economy are capable of accommodating it. Or to put it another way, a phenomenon such as that which is taking place in data processing occurs only when there exists both the motive for its development and the means for its use.

For example, high-speed, modern data-processing machines were not essential to a predominantly agricultural economy such as we had a century ago. If they were, much greater effort would have gone into their development at a much earlier date. For while electronic techniques are new, the concept of automatic data processing is not; others perceived it more than a century ago.

More than any single factor, the change in the structure of the American economy has been responsible for the widespread development of data-processing equipment.

As we changed from a predominantly agricultural economy into a manufacturing one during the 19th Century, it became clear that expanded markets for goods would require more mass-production techniques. Machinery was introduced to increase the productivity of factory workers. It became possible to turn out more and more goods with less human effort. The length of the work week declined. Wages and profits went up. Benefits spread throughout our whole economy.

During the last quarter century, further changes have taken place. In many respects, they are as significant as our changeover from an agricultural to an industrial Nation. Science has moved into the forefront of human activity. Research has grown to be a multibillion dollar a year undertaking. New technology has provided a new impetus for corporate growth. Service industries have proliferated. Our patterns of consumer spending have changed.

As these changes gained force, they soon began to manifest themselves in a number of ways.

For one thing, our informational needs greatly increased. Data assumed new importance. Clerical tasks multiplied. And we soon found ourselves burdened with paper-handling tasks which looked as if they would overwhelm all productive activities.

The evidences of this clerical epidemic are visible in many forms. Today, more people are engaged in the handling, the processing, and distribution of goods and services than are engaged in their manufacture or production. One dollar out of every $8 in wages and salaries in the United States now goes to a clerical worker. White-collar workers in manufacturing industries have increased by more than 50% in the past 10 years, while employment in all manufacturing has increased by only 6%.

Despite these changes in the very structure of our economy, clerical mechanization has not kept pace with production-line developments in the factory.

Admittedly, we cannot compare the productivity of the average office worker with that of the factory worker any more than we can compare the productivity of a brain surgeon with that of a trial lawyer. They do not perform similar functions. But this much we do know—while the clerical force has been getting bigger, the production force has been declining proportionately in size. Clearly, a new pattern of employment opportunities has emerged and with it have come new problems.

Critical shortages in administrative and clerical help appeared for the first time during World War II. Many thought that the situation would correct itself after the war. Instead it grew more acute.

Aside from this growing need for the mechanization of clerical routines and management procedures in almost every phase of organized activity, there is the tremendously expanded need for data processing which has come with our new rate of technological growth and scientific research.

As a consequence, the demands for information are enormous. They are increasing every year. More and more, we have come to depend upon data-processing systems for the information we must have to run our enterprises, administer our institutions, direct our research, and plan our endeavors.

Clearly then, this innovation which has come with electronic data-processing is markedly different from production-line mechanization or even factory automation. For all practical purposes, data-processing systems are universal in the enormous variety of uses to which they can be put.

Regardless of the product or problem, the nature of the enterprise or institution, wherever there is a need

Units of a large-scale data-processing system are tested in manufacturing plant. Unit being checked in foreground is console from which operator supervises processing of problem data.

for information upon which human judgments can be premised, there may also exist a need for a data processing machine.

HISTORICAL BACKGROND

ALTHOUGH DATA-PROCESSING equipment has already become a tool of astonishing versatility, the automatic processing of data is so recent a phenomenon that we need only go back 30 years to trace its biggest and most expansive period of growth.

Advances in business machines during the first quarter of this century had been steady and promising, but they could scarcely have been called spectacular. Although punched cards were introduced during the census of 1890, the data processing industry—as recently as 1930—amounted to little more than a fledgling, albeit a lively one. Production of all business machines for 1929 amounted to $195 million.

Hopeful advances of real promise had been made in accounting machines and punched-card equipment. But while the new industry was beginning to take hold in some places, the great majority of businesses still clung to their old-fashioned clerical ways of getting their work done. Except for a few pioneering companies, industry had not yet sensed the hidden power which was to be discovered in industrial research. Pure science, for the most part, was confined to university laboratories where scientists struggled with inadequate equipment. And even the armed forces, which today set the pace for so many technological advances, were finding it hard to survive on starvation budgets in a climate of public indifference.

Inauspicious as those times were, the business-machines industry was even then probing restlessly and diligently for improvement.

Three significant achievements appeared in the field of data processing in the late 1920's and early 1930's. The first came with the development of a punched card which provided 80 columns of information. This innovation offered almost twice the data-carrying capacity of the older 45 column cards. Another came a few years later with the introduction of an automatic multiplier. Previous machines had been able only to add or subtract. Still another development of increasing portent

came with the invention of an alphabetic accounting machine. Modest though these varied improvements might seem in the light of current technology, they represented substantial advances in the speed, versatility, and usefulness of business machines systems.

Innovations continued throughout the middle 1930's despite the depression which had settled on the world. They gained headway through the years when ominous headlines foretold the nearing of World War II.

Most of these developments came in punched-card equipment and in key-driven accounting machine systems. In the post-war years, long after electronics had profoundly changed the industry, these electromechanical developments continued and new devices appeared from year to year. Far from sidetracking electromechanical improvements, the new computers gave fresh impetus to advances in this field.

For example, before the appearance of electronic data-processing machines, it was thought that 150 lines per minute was the maximum speed to be expected from a printer. Today, many electromechanical printers do 500 lines per minute; some go as high as 1,500. Printers employing other techniques have stepped up the output to 5,000 lines a minute.

With the onset of World War II, there came a swift change in pace. New needs for data processing materialized on a scale undreamed of only a few years before. Much of the momentum came from the urgent demands of science which was suddenly put to work on an unprecedented scale in the development of new weapons. In the design of aircraft and in the development of ordnance, we were confronted with new and prodigious requirements for data. And in the Manhattan Engineer District where work got under way on the atomic bomb, scientists found themselves faced with new dimensions of calculation.

With the war, however, there also came intensive development in the then only little-known field of pulse electronics. To be sure, some manufacturers had been at work in the search for electronic computers as early as 1930. But, under the pressure of wartime work in radar and related equipment, engineers suddenly began to make startling advances in electronics. From those undertakings there came the knowledge which was to make possible the early appearance of the electronic computer.

Both here and abroad, the first two large-scale computers were developed in university laboratories. The earliest, known as the ENIAC, came from the University of Pennsylvania. Europe's first, the EDSAC, was born in the laboratories of Cambridge University in England.

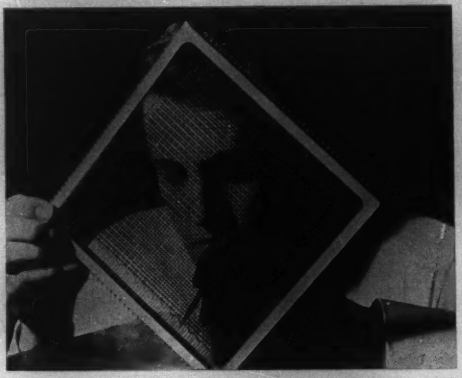
In these machines, the switching and control functions, once entrusted to relays, were handled by vacuum tubes. Thus, the relatively slow physical movements of switches in electromechanical computers were replaced by the swift motion of electrons. By this changeover, it became possible to increase our speed of calculation and perform computations 1,000 times as fast as before.

Here, then, was an instance when our economic theorem on motivation and means came into play. We had reached a period in time where we were presented with data-processing needs in excess of the capabilities of existing equipment. And we had simultaneously reached a stage in technological achievement where a solution equal to the task could be devised. The electronic computer was almost an inevitable result.

This large-scale electronic data-processing system, designed primarily for scientific and engineering computations, executes most high-powered operations at rate of 40,000 per second. Machine's magnetic core memory stores instructions and problem data, any of which can be located and put into use in millionths of a second. Magnetic tapes and drums may be used for additional storage capacity.

Almost concurrently with the use of electronics in computing equipment, there came another major development which was to widen the capabilities of data processing systems and hugely expand their opportunities for application. This new advance was embodied in the concept of what we call a stored-program machine.

At the start, machine instructions were programmed on interchangeable plugboards, cards, or paper tapes. Thus, detailed instructions had to be plugged in, or—as



Technician checks wiring of magnetic core plane. Combinations of electrical pulses on these wires alter magnetic state of tiny cores, each about size of a pinhead. Line of cores, some altered, some unaltered, stands for a certain word or number.

the case might be—read into the machine as the work progressed. Data put into the computer was processed according to the instructions contained in these pre-set devices. Only in a limited way was it possible for the computer to depart from the fixed sequence of its program.

It soon became apparent that such programming techniques as these tended to inhibit the performance of the computer. Consequently, a way was sought to give the machine greater latitude in working out problems without operator assistance.

To make this possible, scientists proposed that the computer be made to store its program in a high-speed internal memory. Thus, it would have immediate access to instructions as rapidly as it called for them. With an internal memory system, the computer could then process a program in much the same way that it processed data. It could even be made to modify its own instructions as dictated by developing stages of work.

The earliest computer to incorporate this feature was completed in 1948. Subsequent machines extended the principle until it became possible for a computer to generate a considerable part of its own instructions.

The stored program concept has made computers far more versatile and useful tools than they might otherwise be. Because the machine is capable of making simple decisions, and because it is capable of modifying instructions, the user is relieved of a vast amount of costly and repetitive programming.

Within a short time, the industry would find it necessary to upgrade machine performance in still other parts of data-processing systems.

Magnetic disk memory provides for "in-line," rather than "batch" processing of information. Electronically controlled read-and-write arm moves at random to any location on magnetic disks, which revolve at 1,200 rpm, to process vast quantities of business data stored on them in form of magnetized spots. This unit stores up to 10 million digits of information.

POSTWAR DEVELOPMENTS

EVENTFUL as the early postwar years were in the development of electronic business machines, the rapid succession of improvements that came with the 1950's made it clear that technological progress had only begun.

Much of the development in this decade was spurred by the increasing use of data-processing equipment in extended business applications.

In the early 1950's the business machines industry introduced medium- and large-scale data-processing systems, specifically designed to take over the onerous clerical chores with which so many growing companies were beset.

Though essentially similar to previous computers in the ways in which they processed data, these new business systems differed substantially in the various parts of their makeup. These changes reflected the particular uses for which the machines were designed. In scientific research, most problems call for relatively small amounts of data to be subjected to intensive machine processing. In business operations, the reverse is more often true. Here we have a need for machines which can accommodate vast quantities of data while the processing, by comparison, is ordinarily quite simple.

Modifications in these new business systems were addressed to the twin problems of input and output.

Early electronic machines had used punched cards and paper tapes for the input of information. Now a method was perfected for the storing of digital information on magnetic tapes in the form of magnetized spots. This new technique provided a new order of input speed 50 to 75 times that of cards. It brought improvement in input, output, and data storage.

While these developments were under way, it became clear that the industry would have to make even greater headway on a number of other counts. Not the least of these was the necessity for more speed—speed not only in processing but in access to memory and program instructions as well.

For in the period after the Korean War, man's needs always seemed to be one jump ahead of the computer's ability to handle the logical and arithmetical labors of his reasoning. The demand had quickened especially in such fields as nuclear physics and space technology where work on the H-bomb and in ballistic missiles presented problems that put a severe strain on the capacities of existing machines.

A substitute for earlier memory devices appeared in the early 1950's when the magnetic core came into use.

A core is a minute ring of ferrite. When strung on a complex of fine wires, these cores can be made up into

Full view of IBM Series 1200 which is designed to help banks cope with growing check volumes. Unit *(left)* is used to imprint checks with magnetic ink. Large unit *(center)* is sorter–reader, which sorts paper checks of varying sizes and reads magnetic information on them into standard IBM data-processing systems via control unit *(right)*. Insert is close-up of reading mechanism.

a high-speed internal memory system. An array of cores —some magnetized in one direction, some in the other— represents items of information. With this technique, items can be located and made ready for processing in a few millionths of a second.

Almost at the same time, other engineers perfected the magnetic memory drum. Access time on the drum was substantially slower than that on the core system, but storage capacity was substantially increased. And while access time on the drum was slower than that on the core, it was much faster than magnetic tape. In some instances, magnetic drums were used in lieu of core storage, especially in smaller machines. Moreover, aside from these inherent advantages, the magnetic drum proved economic; it was lower in cost than core storage.

Meanwhile, other conditions peculiar to business opened the way to still other developments. Not the least of these was the need for systems which would overcome a problem often encountered in data processing, a problem known as "batching."

For example, when magnetic tapes are used to store information in a machine, it becomes necessary for the user to accumulate information in batches before putting it on tape. Otherwise, the process of feeding bits and pieces of information into the machine would be prohibitively costly and time-consuming. But when this limitation is applied in business practice, it also means that each item of information can be only as current as the particular batch in which it is bundled for delivery to the machine. And in ordinary operations, hours, certainly, and sometimes days may elapse between batches.

This limitation is again compounded in a tape machine when the user calls for the retrieval of a piece of information. The machine is forced to search through a long reel of information for the piece. Access is needlessly slow. Time is lost.

Batching and searching requirements of this nature frequently present serious drawbacks, even in scientific work. In business, the difficulty becomes much more acute—especially in accounting procedures. Here we have a requirement which can be met only by what we call in-line data processing.

With in-line data processing, batching delays are eliminated and search time is drastically cut down. Information can be processed and stored in bits and pieces as it is generated. It can be located and retrieved in microseconds.

In-line data processing came with the development in the middle 1950's of random access memory systems.

One of the better-known of these devices consists of a

stack of magnetic disks, storing a total of 10 million digits of information. The disks rotate at 1,200 rpm past access arms which can move quickly to any point on any disk to deposit or retrieve data.

Meanwhile, continuing developments in pulse electronics and solid-state physics led to still newer and better computers. Clearly there were practical limits to the size and capacity of a machine which operated on vacuum tubes. For one thing, tubes are bulky. For another, they demand considerable power. Finally, because they produce heat, they also create air-conditioning problems.

Substitute devices appeared. In some switching functions, the vacuum tube was replaced by a smaller semiconductor diode which had the advantage of demanding less power.

A further advance came when tiny transistors were introduced in the place of vacuum tubes in the computer. Not only could these transistors be packed into smaller units, but they brought greater reliability. The changeover to transistors is now in full swing. Improved systems are appearing each year.

Always eager to move on, research scientists have already advanced to still farther advanced stages in design.

Some are studying the use of microwave phenomena as a medium for performing computer logic. Others are engaged in the study of cryogenics. As always, their objective is to develop a better, more versatile, more useful computer—one which will work faster, store more information, demand fewer instructions, require less power, and occupy less space.

The rate of technological advance in data-processing equipment has astonished even the engineers who are responsible for it. Twenty-five years ago, we were proud of machines which could multiply a pair of eight digit numbers in three seconds. Today we are looking for ways to improve on a machine which will multiply a pair of 13 digit numbers in two millionths of a second.

How far can we go? No one really knows. The undiscovered ways in which computers can quite probably be used seem almost boundless. In the data-processing industry, innovation comes almost as regularly as the changes in season. Notwithstanding the progress that has been made, there are many who say we stand only at the beginning.

THE FUTURE

BUT EVEN IF WE CANNOT SEE what is ahead as distinctly as we might like this much we do know: The business machines industry is an industry of change; it encourages, it induces, and it produces change. Computers will inevitably introduce change in the way we work, in the way we learn, yes, and even in the way we provide for our armed defense. Current research developments even now point the way to some changes which may be nearer at hand than we suspect.

For the moment, computer users are handicapped by the difficulty they have in communicating with these machines. Instructions must be coded laboriously into machine language. Instructions which can be conveyed in a few spoken words to a human being may require hundreds of logical movements in a computer. This becomes a problem when it is remembered that the computer must be instructed in each movement.

The new science of "automatic programming" seeks to make this task an easier and more manageable one. Our industry's goal is to build and to program computers in such a way that they can accept instructions in language approaching everyday English. What we seek is a technique that will tell the machine what to do—rather than how to do it.

Nor is this the end of the line. Ultimately, computer scientists hope to develop machines that will respond to the stimuli of light and sound—machines that will read ordinary printed matter and respond to spoken words.

Some people predict that within 25 years we shall have a common national—or international—machine language for the use of computers. With a common "tongue," all machines would be designed to operate by the same instructional language. A program generated for one machine could then be used by any other, and, the difficult task of creating a program need be tackled only once. Greater co-operation would be possible among users, and progress would be speeded in the science of computer use.

Already, we can point to one significant step forward in the case of machines which read. This development, known as magnetic character sensing, utilizes a technique in which numbers and letters are printed in such a way that they can be read by machines as well as man. Character sensing was developed for the banking industry by computer manufacturers in co-operation with the American Bankers Association (ABA).

The estimated 10 billion checks that are circulated each year in the United States represent a staggering task in data handling for banks. The complexity of this paper handling operation is further compounded by procedures which necessitate that each check drawn on a bank be handled at least six times before it is canceled and returned. Even when business machines were introduced to handle a part of this clerical chore, operators were needed to transfer data from the checks to a form in which that data could be assimilated by the machines.

This gap has now been bridged. By agreement among computer manufacturers, check printers, and the ABA, banking documents such as checks, deposit slips, and debit and credit memos can now be printed with magnetic ink. Printed information relating to the bank of origin, depositor's account number, and other essential data can be read directly by the machine. Only the specific amount of each check or deposit slip need be recorded on the document in magnetic print. And this need be done only once by an operator to process the document through its whole routine.

Another development under way points to further mechanization in engineering design work. Computers may be expected eventually to take over routine engineering tasks, freeing engineers for more productive

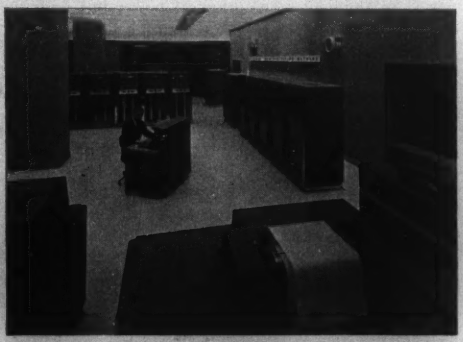
development work. Not too far ahead in the future, engineers should be able to call on computers for the design of highly complex systems. To make the computer work, all that will be required is a statement of the engineering problem in terms of mathematical equations. The greatest difficulty we face in achieving this technique is that of stating design criteria unequivocally and in such a form that they can be programmed into a computer.

Computers, by 1980, will probably be quite different from those we know today. Storage and processing units as powerful as today's largest may be constructed in units the size of a television set, perhaps even smaller. Already we have systems wherein a single computer can be made to serve a number of inquiry stations. Such systems can be expanded to produce still larger networks and aid in the integration of widely scattered business operations. Beyond that, it may be possible to query the computer merely by talking into a microphone to it. Eventually the computers may even be able to answer by voice.

Among the more challenging problems that have attracted the attention of systems engineers is the paper work flow that now gluts so many administrative channels. Information, they say, can be communicated and processed more accurately and cheaply by network-integrated data-processing systems. Some even go as far as to contemplate a time when paper bank checks will disappear in many conventional transactions.

For instance, centuries ago, men bought what they wanted by bartering what they produced. Later, because barter was awkward to handle, men used tokens. Tokens became coins. Eventually, bills were substituted for coins. Finally, bank checks were used in place of coins and bills. A bank account and bank checks are nothing more than devices which are used to store and transmit financial information. The same end, conceivably, could be accomplished through the use of an integrated data-processing network.

Instead of handing an employee his paycheck, a paymaster in 1985 may simply instruct a computer, housed in a bank, to credit the employee's earnings to his bank account. At this point, a chain reaction would begin. The company's account would be debited by the amount of the paycheck. This information would go to the company's accounting machines for processing and storage.



This large-scale electronic computing system solves problems ranging from payroll processing to computation of data involved in design of missile-launching submarines. Magnetic tape units framing operator's console feed huge quantities of information into system for processing. Final results appear on printer in foreground.

Assume, then, that the employee stops at a store to buy something which costs more than he wishes to pay for in cash. The salesclerk would ask for identification. This might be a card, one which would identify the customer to the salesclerk as well as identify him to the computer. The clerk would instruct the bank computer to debit the customer's account by the amount of his purchase. The same amount would be credited automatically to the store's account. Finally, collateral information on the sale would then go to the store's computer for processing with sales, financial, and inventory data. At the end of periodic intervals, the customer would get a statement on his deposit and all computer transactions.

Still other scientists, aware of the difficulties their colleagues experience in screening sources for data on known discoveries, have turned their talents to the development of what they prophetically call "information centers."

The science of information retrieval by machine is presently under rigorous study. As our society grows larger, the information it generates will increase. With this accumulation of information, the task of finding what one is looking for becomes an increasingly difficult and time-consuming one. Today, for example, if one wishes to know the current state of research in a certain area of electronics, it is virtually impossible to screen all the sources. The best libraries may lack important reports or obscure but useful books. Not even the most carefully compiled abstracts can guarantee against omissions.

Information centers of the future would be designed to collect, catalog, and disseminate information electronically by machine. It could process the information with greater emphasis on ease of retrieval. It could provide more copious cross-references and more detailed subdivisions of subject matter. Queried about a subject, it could provide specific source references. Or, if asked a question, it could give a direct answer.

Think, for a moment, what this would mean. For the first time in recorded history, we could have immediate and ready access to more information than we have ever had instantly available before. A man might never have the ability to know all that he might want to know, but he would have the means of finding it as he had need.

It is possible, of course, to speculate endlessly on the exciting years ahead. Whenever two systems engineers are brought together, the range of machine applications appears to widen. The last quarter century has been called momentous; it has also been prophetic. We can see infinitely more ahead of us than we have put behind us.

Everywhere the pace of technological advance has quickened. The movement is surging in all fields of endeavor. During the next 25 years, man will journey into space. Some say he will reach the nearest planets. He will look about him on earth. He will pose questions and search for knowledge. He will make discoveries not yet imagined.

It is in such a world, and at such a time, that he will have greater and more pressing need for business machines than ever before. These needs, in turn, will dictate machine advances.

What will these advances mean? As I see it, they signify continuing and hopeful advances in human progress. And because these machines have so many applications, because they can be used in so many ways, I do not limit their contributions to material abundance. To me, these machines hold out the promise of progress in the use we make of our time, progress in the way we employ our talents, progress in the search we make for learning and knowledge. Put all these things together, and it may not be too much to hope that these machines, in some way, will help us to keep those very values which make the human being so distinct and his life so worthwhile.

Computers and Automation

E. L. HARDER
FELLOW AIEE

IN THE BRIEF SPAN of years since the closing days of World War II, we have witnessed a technological development in computers of such broad proportions that it is still impossible to appraise its far reaching effects adequately. Perhaps, the best way to express the enormous influence of this revolution is simply to point out that practically all of man's actions in producing the necessities and luxuries of life fall into two categories, namely his mental and his physical work. All of his mental work has to do with the processing of information in some form or other, and the close relationship of the computer to the human brain and its functioning needs no elaboration here. It should have been expected that nearly all of the operations of the civilized world, in which the human brain is involved to a greater or lesser extent in carrying out the task, could be aided by a technological development which performs accurately and at high speed, some of the functions of the brain. This is variously called computing, or information- or data-processing. Its field of application is as broad as human knowledge and is far beyond the comprehension of any one individual. However, large teams of scientists and engineers are currently at work in many of these compartmented fields of knowledge, learning how to adapt and develop the automatic processing methods of the computer to the needs of their particular fields.

The revolution in computing has progressed to a point where two clearly distinct areas of computer automation are evident, the one associated with the automation of physical processes, controlling and measuring power machinery and vehicles, and the other having to do with the automation of man's clerical and mental work.

In the former, one can trace the stages of development starting with the primitive tool. Next came the power tool in which the forces of nature were harnessed to augment man's physical power but with the entire intelligence for its use remaining with the man. We have witnessed the gradual additions of intelligence to make this tool perform more and more automatically. The earlier elements of intelligence were simple computing devices, usually in the form of analog elements built directly into the mechanism of the tool. The potentialities of punched paper for sequencing processes was early recognized in the Jacquard Loom and the player piano. Most servomechanisms have some form of analog computing function built in. However, as the ratio of intelligence to power has increased, the computer is beginning to emerge as a distinct organ, separate from the power handling facilities and providing for the sequencing, the optimizing, the computing, and the data processing for the controlled process.

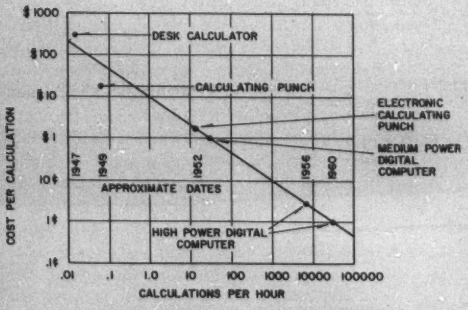


Fig. 1. Computation cost vs computer speed.

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Fig. 2. PRODAC, programmed digital automatic control (similar to unit, *right*) at work controlling a reversing roughing mill (*left*, seen from control pulpit) of the Jones & Laughlin Steel Company at Aliquippa, Pa., near Pittsburgh.

In the field of computers for processing man's mental and clerical work, the early aids to calculation—the desk calculator, the slide rules, and the cash register—have grown through the stage of business machines capable of performing simple calculations on large numbers of similar documents. They have grown to the medium- and large-scale internally programmed, automatic computer, capable of carrying out long sequences of business, engineering, or military calculations. The high-speed internally programmed calculator brought, for the first time, a tremendously lowered unit cost per calculation (Fig. 1) with its explosive economic effect of broadening the base of applications to which computers might profitably be applied. For example, computation requiring 2 weeks on a desk calculator and costing $300 in 1947 will cost 1¢ on a high-powered computer of 1960, a reduction of 30,000 to 1. This single economic factor has been a major influence in extending the computer into the processing of complete sequences of business calculations such as the payroll, the inventory and stores program, and the accounting of a factory.

In engineering, the increased computing power and lower unit cost has been put to work in solving many previously intractable technical problems as well as carrying out the complete logic of design for more standardized products.

In addition to advances in the computer itself, still proceeding at a revolutionary rate, the science of programming is undergoing intensive development to reduce this tremendous bottleneck between the job to be done and the machine. It requires a little imagination to realize the vast potentialities that remain practically unexplored as the power of the mechanized logic of these computer and programming developments are brought to bear on the sequencing and optimizing of controlled processes.

In many industries, automation has reached a high state, with feedback control, or simply with sequenced controls, eliminating most of the manual operations previously required in mass production processes. The transfer machine for complete machining of an engine block, the integrated four or five stand tandem cold-rolling mill for steel strip, and the paper making machine are but a few examples. For large production of an invariable product, this form of automation has reached high development.

However, where the product or ingredients are variable, and where greater and more flexible intelligence can profitably be applied, computer techniques are being rapidly incorporated into the automated system. This is exemplified by the programmed digital automatic control for a blooming or slab mill (Fig. 2), the digitally controlled skin or profile mill for aluminum wing structures, or the automatic economic dispatching control of an electric power system.

It is these latter phases of automation of physical systems, together with the automation of mental and clerical work, that are to be treated. Both are closely associated with computer development. The relation of computers to automation will be treated by outlining the important developments that have been taking place in several areas. Taken together, these illustrate the revolutionary character of the development and indicate the progress that can be expected in the next several years. In addition to the computer itself, we shall discuss developments in programming; in engineering applications; in business, military, and Government applications, as well as in the translation of language, the retrieval of information, and other diverse fields of information. We shall consider the computer in data logging and control. We shall consider all of the accessories developed for data processing as well as the computer techniques themselves as a "bag of tricks"

out of which much practical automation is being accomplished short of the full computer.

DEVELOPMENTS IN THE COMPUTER

THE FIRST LARGE-SCALE, internally programmed, electronic digital computer was the ENIAC, completed about the end of World War II (Fig. 3). This machine had 18,000 vacuum tubes, and used vacuum tube high-speed storage. It used a 600-entry wired storage for a function, namely the drag function, since the computer was intended primarily for ballistic problems. Magnetic tapes were notably lacking at that time, but were soon developed. Computers installed since that time are shown in Table I. The four panels shown in the background in Fig. 3 are the initiating panels, cycling panels, and the two master programmers. On the right is shown a function table. The two master programmer panels determine the sequence of operation in the solving of a problem in which panel numbers are added, subtracted, multiplied, and divided. Also in these panels are stored numbers for use in a later stage of the solution.

The most notable developments since that time have been the mercury delay line storage, then the Williams tube high-speed, random-access storage, and the magnetic-core storage which soon succeeded it and which now forms the high-speed memory of most modern large-scale computers. For computers of medium to low speed and cost, the magnetic drum has been highly developed. More recently, the demand for larger random access, of lower cost per bit, principally for the storage of active inventories of business items, led to the development about 1956 of magnetic disc and multiple magnetic tape memories. The Ramac unit of The International Business Machines Corporation (IBM) is a disc memory operating in the fashion of a juke box and storing some 5 million 6-bit characters, arranged as 50,000 separately addressed, 100-character records. The average access time of 1/2 to 1/6 seconds, depending on the number of reading arms, is adequate for the transaction rate of many businesses having inventories within the 50,000 record size.

Fig. 3. ENIAC, operating at the University of Pennsylvania in 1947, was the first large-scale electronic digital computer.

Table 1. General Purpose Digital Computer Systems Installed January 1959

Computer System	Number*
Large Scale (Magnetic tapes and microsecond arithmetic)	316
Medium Scale (Magnetic tapes and millisecond arithmetic)	348
Small Scale (No magnetic tapes, but internally programmed)	1,370
Miscellaneous (Card calculators and others)	5,166
TOTAL	7,200

*Figures were taken from John Diebold Associates publication *Automatic Data Processing Service Newsletter*, vol. III, no. 17, Jan. 12, 1959.

Since 1956, solid-state techniques have been used to an increasing extent, so that as of 1959, several all-transistorized or magnetic computers are on the market with substantial increases in both speed and reliability.

Magnetic tapes are used on all large and many medium size computers today. The 15,000-cycle frequency (200 characters per inch times 75 inches per second) characteristic of 1956-57 has been stepped up by 4-to-1 to a 62,500-cycle frequency (555 characters per inch times 112.5 inches per second) or higher. Wide tapes are used on some computers further multiplying the information transfer rate from a single tape transport unit.

The first high-speed printer (600 lines per minute) was developed about 1954 for the UNIVAC computer. Facsimile printing at 1,000 lines per minute and still higher speed photographic printing from the Charactron have since been developed. Off-line printing has become the rule for most large installations, and for many medium installations with magnetic tape, to conserve the valuable computing time. Buffering to permit simultaneous read, write, and compute, first used for the serial business computers, is now available for high-speed, parallel scientific and engineering computers also, to increase the speed for problems with large input-output requirements.

Of note during the last 5 years has been the greatly increased use of small drum computers, priced under $100,000. Over 600 computers in this bracket have found their way into as many diverse applications, ranging all the way from research on "home permanents" to on-line reduction of data on a critical atomic facility. There is profound significance in this broadening of the base of computer usage—in having this many diverse groups extending computer technology into so many avenues of human effort.

SAGE COMPUTER

LANDMARKS of present advance for large-scale systems in service are the computers of the SAGE system for continental air defense (Fig. 4). Working with unprecedented reliability on an around-the-clock schedule, such computers process constant streams of radar data, perform complex computations, and present visual displays of the air situation to U. S. Air Force personnel. Their duplex facilities assure their 24-hours a day primary air defense mission while scheduled maintenance is being performed and training programs carried out.

Most important for automation, and far more difficult to express, is the progress during this same period in computer techniques and accessories. The general-purpose computer represents an important use but far from the only use of these techniques. It is the availability of this tremendous array of adaptive and peripheral devices that takes the computer out of the laboratory and into practical automation.

DATA LOGGING

THE ABILITY to process data rapidly implies the necessity to gather data rapidly and efficiently, hence the development of data logging equipment. Data logging requires, first of all, transducers from all types of measurements into analog or digital form. These include currents, voltages, power measurements, rates of flow, pressures, temperatures, weights, times, counts, thicknesses, compositions, speeds, hardness, viscosity, moisture content, density, concentration, and all manner of other physical, chemical, metallurgical, atomic or other conceivable properties. An ever-increasing range of such transducers is becoming available of improved quality and reliability. Logged data becomes much more valuable with the ability to process it rapidly, with increasing knowledge of what action to take as a result of the processing, and with automatic facilities to take the indicated action.

Generally, to gather such data, it is necessary first to schedule its taking. This requires programming or timing equipment. Often analog-to-digital conversion equipment is required where the basic transducers develop analog outputs. This equipment may be time shared among a large number of measurements, requiring accurate and high-speed conversion equipment.

Data logging usually requires the typing or printing of some or all of the data for monitoring purposes and the recording of some or all of it for later processing. Frequently, the availability of the data leads to a requirement for alarms at limiting values, and perhaps the more extensive action of automatically changing a set point or otherwise altering the process being monitored. The final records may be on paper tape, magnetic tape, punched cards, or other suitable medium. In some cases, the data logging feeds directly into a computer which processes the data on the spot and gives out only the desired processed results instead of the multitudinous items of input data.

Equipment in considerable variety is now available for all of the functions previously described. However,

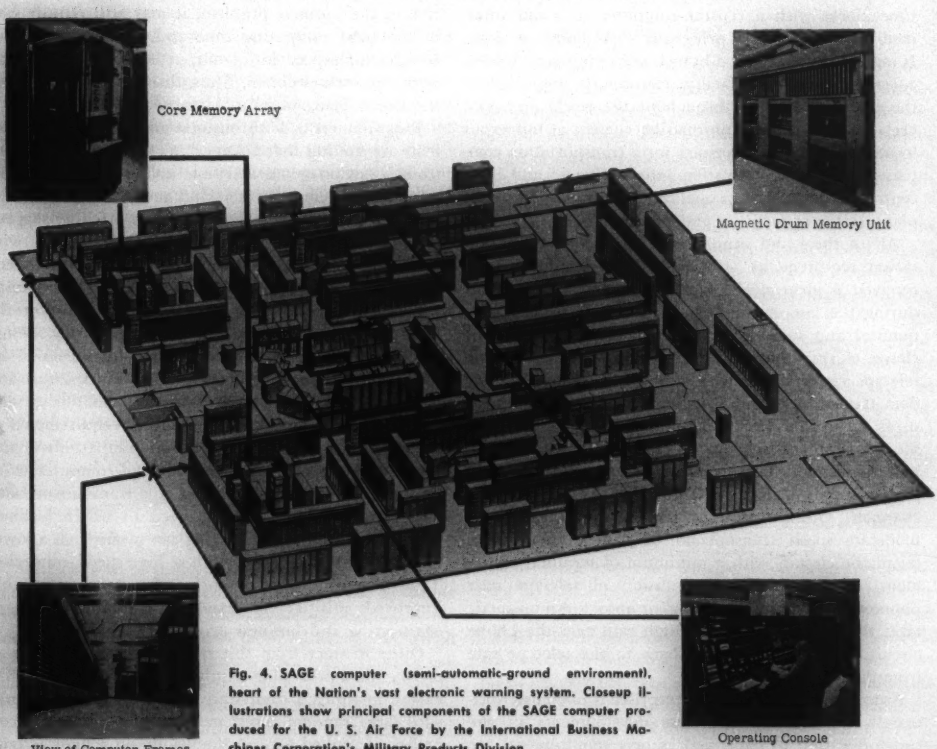

Fig. 4. SAGE computer (semi-automatic-ground environment), heart of the Nation's vast electronic warning system. Closeup illustrations show principal components of the SAGE computer produced for the U. S. Air Force by the International Business Machines Corporation's Military Products Division.

as the applications grow, the conditions to be met continue to expand and we should expect to see over the next several years tremendous advances in both ideas and equipment for filling the needs in this area of automation.

DATA COMMUNICATION

THE LOGGING AND PROCESSING of data also implies a need for communicating it from one point to another, or from one computer to another at the same point. We may cite the continental defense requirements for transmission of data from many points to the central computers of the SAGE system (Fig. 4). In an industrial operation, we may have the transmissions from many district offices over a network of teletype circuits to a central order-processing computer. It may be necessary to extend the services of a central high-powered scientific computer to the engineering departments at other divisions of the company at remote locations up to several hundred miles away. It may be necessary to transmit data from field tests of a missile or a turbine installation to a remote computer, either on a permanent or temporary basis.

It may be necessary for a large number of telephone installation and service men to communicate with a central computer for their daily orders for supplies, or for the workers of a factory to communicate through time clocks with a central computer to avoid intermediate operations in processing their hours of work. It may be necessary for a branch of the military to keep a central computing facility continually appraised of the status of supplies throughout the world and, vice versa, to keep certain information current at numerous locations. It may be necessary for a transportation company to transmit reservation information to and from central points as well as operational information, flight plans, status of facilities and products.

All of these and innumerable other data-communication requirements associated with computers have received a great deal of attention and development during the last several years in order to provide economical and suitable services for all of the different classes of requirements. These range from the simple teletype circuits now with new checking features for data transmission, the 80-column card transceivers for using up to four 11-card-per-minute transmissions over four separate carriers on a telephone voice channel, and the magnetic-tape to magnetic-tape transmission at higher speeds utilizing the full capabilities of voice channels. Other variations include the cardaphone, moderate speed transmission of data over ordinary telephone circuits with a minimum of terminal equipment, and the rapid transmission of teletype over phone circuits by first "playing" it onto audio magnetic tape, then transmitting at a high rate over the phone circuit, and finally stepping back to the teletype rate from the received audio tape.

Automation of far-flung enterprises is obviously intimately interlinked with these developments in the communication of data, and as new requirements are continually arising, together with a pressing need for better solutions to the old problems, the developments in this area in 1959 are surging forward at an unprecedented rate. It can be expected that this communication adjunct to automation will see great advances in the next several years. In turn, the automation of communication circuit switching and accounting is benefiting by the advances in computing techniques.

GENERAL AND SPECIAL PURPOSE COMPUTERS

ALTHOUGH LARGE-SCALE COMPUTERS originally were developed along separate lines for business and scientific purposes, two seemingly contradictory trends are now evident. One is the definite trend toward the common computer or computing center which has the proper complement of equipment to meet all of the large information processing requirements of the plant or group of plants. Originally, it was felt that the large input–output requirements and special storage requirements of the business problem required a separate type of machine from the engineering or scientific problems with their comparatively smaller input and output and very much greater computation requirements. It has since been found that even though the input–output of the engineering problem is small relative to the business problem, it may still require half of the total computing time and, thus, economically justifies high-speed input–output equipment, the same as the business problem. Thus, this distinction between the two is being rapidly obliterated.

Programmers of both business and engineering problems are finding that a large high-speed memory is extremely advantageous and time saving in the programming of problems of either kind and, thus, this requirement for an expensive element of the machine suggests the pooling of most problems on a single facility with very ample high-speed memory. The business operational problems of production control, and engineering which may combine in one close-knit operation the large computational problems of engineering design together with the references to large quantities of information on stocks, processes, time values, costs, and parts, naturally militates in this direction.

The supposition of low computing requirements of the business problem are based on compatibility with input–output speed. However, buffered computers with multiple tapes and higher speed tape transmission, may well raise the input–output speed to where business problems as well as engineering can profit from a lower unit cost per calculation with a high-speed computer. Thus, new computers on the market have remarkably improved abilities for handling combined loads of engineering and business problems.

Quite distinct from this trend is the appearance of on-line data-processing equipment such as the IBM RAMAC in which a comparatively inexpensive computer with large random access memory of ½ second access or less, is applied for continuous use on a high activity

business operation, and tends away from joint use consideration. This trend to special-purpose computers, is continuing over a broad area of operational and industrial problems. The specialized banking computers, the reservation computers for airlines and railroads, the large storage computers for air traffic control or for the continual processing of substantial inventories of many types, all trend toward the on-line computer, specialized or not. In industry, one finds the digitally controlled machine-tool director, intermediary between the large general-purpose computer for developing the tool path and the phase-modulated tape for the individual tool.

The PRODAC, programmed digital automatic control for mills and processes (Fig. 2), provides the necessary components of memory for storing the mill program, the necessary reading devices for quickly changing it to another program for a different mill operation, the necessary comparison or computing elements for making digital comparisons between the mill settings and the programmed values for actuation of the driving servos. Such a device has little use for the large repertoire of commands of a general purpose computer, but special attention must be given to reliability since the unscheduled maintenance of most general-purpose computers of the past could not be tolerated in such an application.

Thus, industrial control may utilize many of the computer techniques, incorporating them in particularly reliable forms especially for the important higher speed operations. The memories, the logic circuits, the programming and scheduling facilities, the reading devices, the data logging mentioned previously, including the analog-to-digital conversion equipment, all find their place in the automated mill, but frequently in specialized form. Somewhat further from the inner workings of the physical mill itself, the general-purpose computer finds its place in the planning, scheduling, and processing of the data on a "one step removed" basis. It is supplied with data and programs to be processed in accordance with the need of that particular industry. This mill or operational use of the general-purpose computer compares with the general-purpose computer in the manufacturing plant for the control of materials and stores, for the accounting operations, for production scheduling and optimizing, for payroll and records, and for the analysis of operating data.

ANALOG COMPUTERS

THE GROWTH of analog computers, while less spectacular, has been steady. Most widely used are the electronic differential analyzers for the solution of regulation, dynamics and other problems of physical systems which can be expressed in differential equations. Network calculators and field models and the large passive element computers for transient and vibration analysis of systems and structures constitute another large class. The vast majority of all special-purpose computing devices associated with machinery, control, regulation, and instrumentation are analog in nature, at the present time. The use of analog computers for navigation and fire control directors, and for industrial control and simulation greatly exceeds the use of digital techniques in this area.

Principal developments responsible for the increased use of analog machines are: a full order of magnitude of accuracy improvement, the introduction of centralized control, and the substitution generally of static electronic devices for servo multipliers and function generators, together with revolutionary detail improvements.

The digital read-in and read-out and other automatic features have further enhanced its use while the development of analog–digital conversion equipment has led to the combined use of analog and digital facilities for large simulation problems requiring the capabilities of both computers.

Although primarily restricted to the engineering and scientific field, the number of analog computers in many large industrial establishments is quite comparable to the number of digital computers. A large analog installation is generally made up of a number of smaller analog computers, which can be used independently or connected through central control.

DIGITAL COMPUTERS OF THE FUTURE

FROM WHAT HAS GONE BEFORE, it can be clearly seen that the future of computers does not hinge entirely on increases in speed, memory size, or logic, but also on the expansion and utilization of the tremendous range of facilities already developed, which are taking computer techniques and mechanized logic into all phases of industrial operation.

Nevertheless, speed and memory size and extent of logic, which can be economically justified, still have a strong bearing in some of the more interesting and sociologically important developments of the computer of the future. If the large-scale computer of 1958 is described as a commercial unit with a one megacycle rate, using vacuum tubes capable of adding 40,000 ten-digit numbers or multiplying 4,000 in a second, then its counterpart in the development laboratories is a solid-state computer with a pulse rate of 40 mc. Combined with new technological ideas, it has superior computing facilities as well as memories, buffering, and flexibilities, giving it an effective computing power of the order of 400 times the commercial unit of the last few years.

This laboratory unit with its 40-mc rate corresponds to a decision element speed of 25 millimicroseconds operating time. At this speed, the length and stray capacity of wires is certainly becoming important. However, with decision elements operating in 2½ millimicroseconds, which have been proved feasible using solid-state techniques, the computing circuitry of 1960 being developed in the laboratory will be up against serious time delays in the wire. Although the theoretical time

for electromagnetic waves to travel one foot is one millimicrosecond, end effects increase this to 1.7 millimicroseconds for a one-foot connection. This is $\frac{7}{10}$ as long as the operating time of a decision element of $2\frac{1}{2}$ millimicroseconds. Developments on the horizon make it quite evident that this decision element time will decrease below 0.25 millimicroseconds. (A semiconductor switching in 0.05 millimicrosecond has been announced by *Electrical Design News*, January 1959, page 3.) The one foot of wire at this stage would represent a delay seven times as long as the element and would render the development of the element worthless.

This spells but one thing—microminiaturization. Although miniaturization studies are proceeding on all solid-state devices, a great deal of interest has been focused on the thin film and cryogenics.

The cryogenic element is based on the phenomena that wires held at about 420 F below zero can be switched into and out of superconductivity by a small magnetic field which can be produced simply by a current in one wire passing over another. The simplest cryotron is, therefore, a crossing of two wires. Different materials have different transition temperatures so that the controlling wires can always be kept superconducting and require no energy. Any number of elements can be switched from a single element. An external d-c current source provides the basic power through each wire.

Work at Massachusetts Institute of Technology reported by Dudley Buck at the Eastern Joint Computer Conference, Philadelphia, Pa., Dec. 1958, indicates there is reasonable possibility from experimental work that such cryotrons can be made in batch processes by selective etching of thin films of conducting material coated on insulators utilizing electron beam techniques to select the parts to be etched, and leaving a network of lines and elements so fine as to be invisible to the human eye with the most powerful optical microscope. The lines in this array would be $\frac{1}{10}$ micron in width or 1,000 angstrom units compared with 4,000 to 8,000 angstroms, the wave length of visible light. Cryotron elements would have a minimum spacing of one micron apart in each direction giving a theoretical maximum of 10^8 cryotrons per square centimeter on a thin film. Successive thin films can be shielded by superconducting layers. Allowing several cryotrons to a logic element and a tremendous space (relatively) for interconnections, a packing of 10^4 logic elements per square centimeter should be attainable. The complete arithmetic unit logic of a present large-scale computer reduces to not over a cubic inch on this basis. Needless to say, the lead lengths in such an array would be amply short and the time constants should be short enough to permit another decade of advance below the $2\frac{1}{2}$ millimicrosecond decision element time cited for 1960.

Philosophers, while admitting a faint similarity between some functions of the brain and a computer memory, have always pointed out the disturbing fact that a sufficient number of elements to compare with the brain would require a unit the size of a large office building. However, a spacing of cryotrons one micron apart on thin film compares directly with the density of neurons in animal nerve tissue.

The recent studies in which computers have been used to simulate self-organizing mechanisms in which information is stored through the connection of elements rather than their state provides a more interestingly close resemblance to the brain. Such mechanisms can be arranged to learn a desired response. They resemble the brain in that the removal of part deteriorates rather than completely destroys the functioning. The remainder contains the learning power to improve itself again. This presents the interesting possibility of logical structures of unprecedented reliability and of entirely new computer philosophy. Thin film cryogenics holds promise of sufficiently large arrays at reasonable cost to study self-organizing mechanisms adequately. This may enable us to learn more of the functioning of the human nervous system and also to derive ideas from nature for the further development of computer logic.

Development of the ideas, the logic, and the programming philosophies for utilizing these inherent capabilities will keep scientists busy for a long time. It is amply evident that space-age automation will not be hampered by any ceiling in the advance of computer technology.

PROGRAMMING

THE ASSEMBLY PROGRAM, which is a necessary adjunct to any large computer installation today, brings to the programmer in the form of a package program most of the automatic programming developments to date. He writes his program in the simplest form and then "assembles it" on the computer. The assembly program converts his abbreviated program into a complete machine language program by performing the following typical operations, all formerly done by the programmer himself:

1. It converts the simple symbolic names for the commands into decimal or binary machine codes as required.
2. It brings into the program any needed routines from the library tape.
3. It allocates memory space and inserts correct addresses in all instructions.
4. It detects common errors.
5. It converts from our decimal number system to the binary number system if used.
6. It condenses the program to a tape or compact card form.

The compiler program, such as Fortran for the IBM *704*, goes a lot farther. In using an assembly program, the programmer must write each step (except for subroutines) albeit in abbreviated form. With the compiler, this is no longer necessary. He simply writes the mathematical statement for the program to be prepared

and the compiler (Fortran means "formula translation") translates this into a machine program with an efficiency of 5- or 10-to-1 compared with writing out each step. Fortran is primarily for scientific or engineering problems.

In many fields, specialized languages are prepared enabling the programmer to express the problem as simply as possible in terms native to that field. Thus, a language has been written in which a steam system can be conveniently described to effect the heat balance solution with any arrangement of turbines, heaters, pumps, and boilers.

Another language has been written for dealing with words in a language for language translation. In this case, facility in dealing with "strings" of words is an objective.

A language for describing the desired tool path, rate of feed, and tolerance for digitally directed machine tools, permits the description of straight lines by two co-ordinate points, or one point and tangency to a circle of given center and radius. Similarly, other regular geometric shapes are used in a manner native to drafting.

A language was described recently for point mechanics, enabling any problem in masses, springs, levers, torques, and frictions to be simply described.

In each case, a program is then written to bridge from the problem statement in the use-oriented language to a machine program for solving the specific problem. In the mechanics language cited, the associated program prepares a Fortran program, which can then be compiled by Fortran into a machine language program. However, a compiler from the Fortran language could be written to other computers than the IBM *704* for which it was intended. This has, in fact, been done, "Fortransit" making the conversion of a Fortran written program to the "IT" compiler for the IBM *650*.

The universal language is the rallying point for work on machine compatibility; running programs on one machine that have been written for another. If written at a high enough and generalized enough level, hopefully in a "universal language," this may be done. The limitations today are so great that practically all programs are written in a language of the machine on which they are run. However an increasing number are written in a high-level language such as Fortran, and are far more susceptible to translation than direct machine language programs.

It is fervently hoped by everyone with a substantial stake in programs that good workable solutions to the compatibility problem will evolve in the next several years.

Considerable work has been done on compilers for business problems. Here the general concepts involve first a complete and orderly arrangement of all data into addressable records and files. Second, it must be possible to state explicitly what operations are to be performed on this data and the form and arrangement of outputs. Finally, from the characteristics of the specific machine, the compiler must prepare a working machine-language program that will accomplish the desired operation.

The concept of report generator implies the ability to specify conveniently and quickly a new derivation from the data needed for certain management decisions, a facility utterly hopeless without a high-speed computer. The possibilities of this are being actively explored by many management groups as a means of lessening routine data.

DIGITAL CONTROL OF MACHINE TOOLS

THE IDEA of using numbers expressed as holes punched in cards or tapes to control the multiple motions of a machine tool, was first presented to the U. S. Air Force early in 1949. In the 10 years following, both the philosophy and equipment have been developed and over 100 contour milling machines are now either in use or under construction using the resulting principles. These are principally the skin mills and profile mills in the aircraft industry used for the machining of complex wing sections. Hundreds of other digital machine-tool applications are in use or under development for a wide variety of machine tools. Typical positioning applications are the placement of components on printed wiring boards, or the positioning of the work and tool turret in a large sheet-metal punch press.

For the contour milling operation, the calculation of the tool path presents an awesome problem, work on which started at MIT under Air Force contracts and has now been taken up by a joint industry effort. This is resulting in computer programs for converting the desired cuts into tool center paths.

To date, the starting point has been the engineering drawing. However, ideas for getting directly from a simpler specification of the desired shape to a tool path program for machining, bypassing the drawing, is developing. It appears that the rules for filets and curvatures, through which the draftsman develops from the basic requirements and dimensions into a finished object, may very well be programmed for a computer. However, this is for the space age ahead.

ENGINEERING APPLICATIONS

IN MECHANICAL and electrical engineering, computers have been particularly important in the design and application of machinery and systems. Civil engineers have found it invaluable for the extensive earthwork calculations involved in highway and seaway construction and the calculation of structures.

In engineering design, the earliest problems attempted were the scientific problems which could be quite well-stated mathematically but many of which it was impossible to solve practically without the aid of the computer. These included the diffusion calculations for the nuclear reactor, the higher natural frequencies of turbines and compressor blades, and the modes, vibrations and frequencies of other more complex mechanical shapes. In design, the computer was widely used for the performance calculations in which the designer completely specifies a conformation of the device and

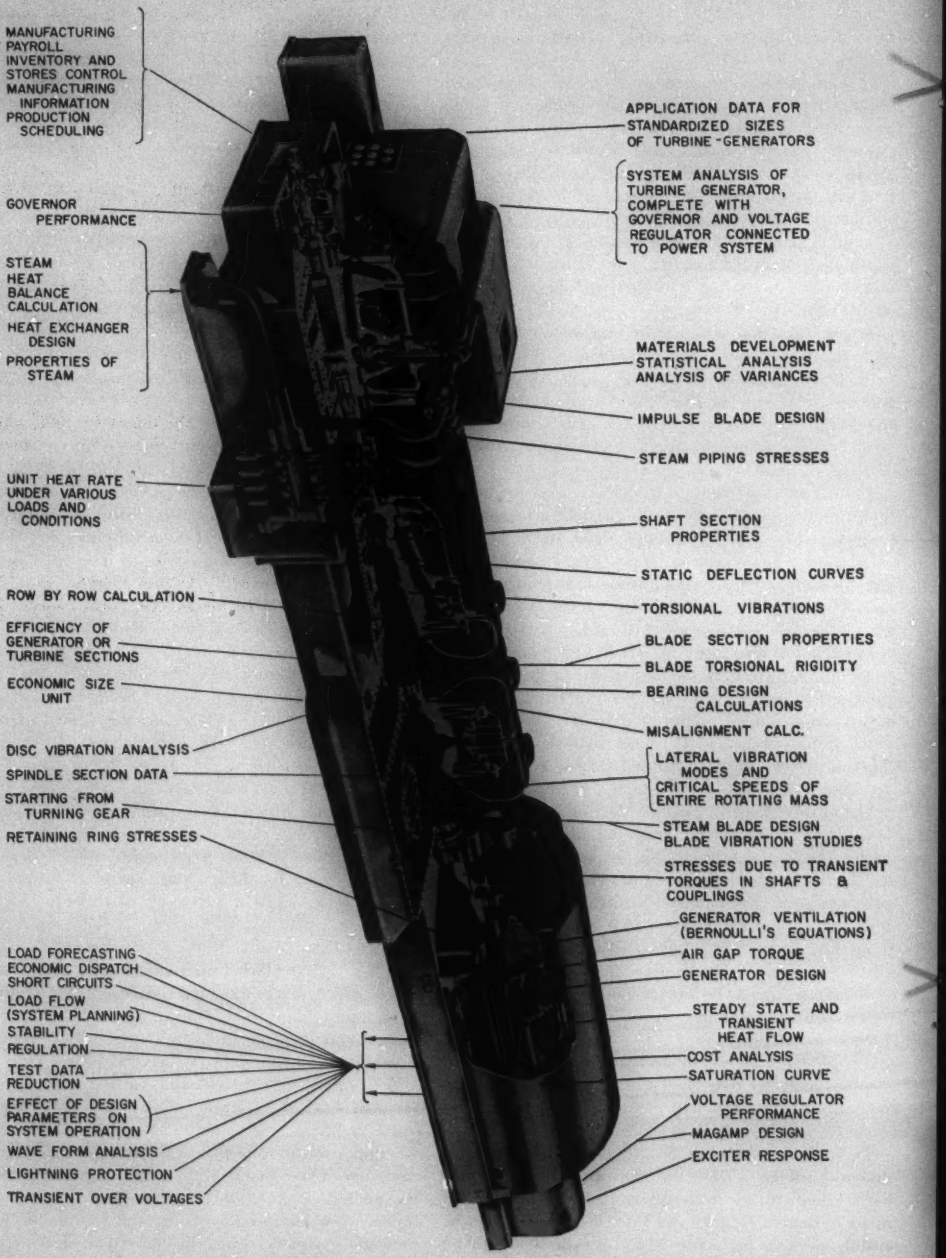

Fig. 5. Typical calculations currently made by computer in the design, manufacture, and application of turbine generators. Exploded view of 135,000-kw machine built by Westinghouse Electric Corp., for the TVA Shawnee Station.

calculates how this will perform as a step in revising and developing his design.

The next stage of computer application was the complete design to specifications of a product. Usually this product was a member of a line in which the individual member had not been designed, but the plan as to how it would be designed had been developed in advance. The procedure consisted of entering into the computer the specifications of the desired unit and sufficient information for the computer to select a trial design. It then made the performance calculations on this design and compared the performance with the input specifications. If these did not agree, being either too low or too high, the computer made certain changes in the design, recalculated the performance, and continued around this loop until a design was produced which met the specifications. This was then printed out. This type of program required skilled design engineers in its preparation since only they knew what to change and in what order to make the changes in order that the design surely converged to the desired specifications.

Next came the optimizing design in which all of the work of the preceding paragraph was done, but then the computer was not satisfied with simply a good design but was programmed to range over permissible variations in materials and arrangement, calculating various designs within the permissible bounds and available materials, all of which met the specifications. The optimum design was then selected and printed out by the computer usually with several alternates for the designer to compare as well.

Typical calculations currently made by computer in the design, manufacture, and application of turbine-generators are shown in Fig. 5.

In all the design work up to this point, the engineering has been treated as separate from the rest of the complete order-handling and manufacturing operation of the plant. True, certain cost data and information regarding stocks of materials had to be fed into the computer in order for it to optimize the design and keep within the available parts; however, this constituted a fairly trivial liaison with the rest of the operation.

COMPLETE ORDER-HANDLING PROCEDURE

With the design procedure by computer becoming quite well understood, the possibility presents itself of incorporating this step with the entire series of steps in the interpretation, commercial handling, engineering, design, the preparation of manufacturing information, the shop scheduling and control, the accounting and shipping of the order.

The computer program or series of programs in a plant that deal with the processing of one individual order as it goes through all of the various operations required of it, may be viewed as both drawing information from, and feeding information to, the other mass business programs of the plant as shown in Fig. 6. This has been simplified to show only a few of the many operations performed on an individual order and also only representative of the major "mass" programs for handling the materials, payrolls, and accounting of the factory.

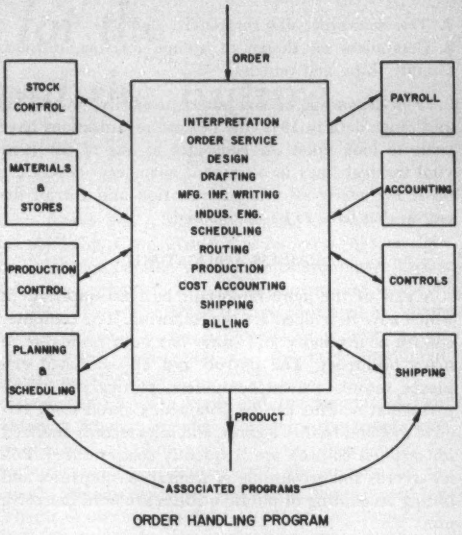

Fig. 6. A straight-through order handling program must be kept updated by the mass data programs of the plant and, in turn, feed them information developed on a particular order.

A number of ambitious programs are now under way for carrying out much of the interpretation and design and preparation of manufacturing information by computer. The work done to date has amply demonstrated the need to consider this as a single over-all system problem. The extension of computer technology in the manufacturing operation will continue both in the mass business problems of the plant, and also for the straight-through order handling procedure including design and manufacturing.

DEFENSE APPLICATIONS

Defense requirements have directed and financed a large part of all computer development and automation. To begin to picture the range of use in various defense operations is quite hopeless. Computers are associated in some way with every operation. Some of the larger uses publicly announced are the following:

1. The SAGE system for continental defense processing data on all targets, weapons, and other factors of interest (Fig. 4).
2. Missile and gun-director computers and navigation computers.
3. System design, evaluation, and simulation computers.
4. Supply and inventory computers for all military parts.
5. Air traffic control.
6. Logistic and operation research facilities.

7. Test data processing computers.
8. Computers for design of atomic reactors, missiles, aircraft, ships, and vehicles.

From depending on computers primarily for ballistic and range data in 1945, the defense organizations have come to look upon the computer as one of the most vital survival links in an atomic space age—depending on it for nearly all vital information and for all decisions that have to be preplanned.

BUSINESS APPLICATIONS

A FEW of the more important business applications which have developed are the following. The computer control of inventory and stores has been profitable in many businesses. The payroll and all associated employee records are on computers, particularly where peripheral benefits can be obtained. Capital stock records, tool and facility records, and sales records analyzed for business control, are frequently computerized. Policy records and accounting of insurance companies and billing accounting of public utilities are both extensive uses.

Mail order houses and the repair parts and shipping stocks of many businesses are being placed on on-line computers.

All forms of accounting, traditionally using business machines, are being considered for larger scale computers and many profitable conversions have been made. Thus, computers are appearing in banks and commercial houses, hospitalization, and finance companies.

The use for operations research, for production planning and scheduling, for business decisions, for simulation of business operations to study alternatives, and for linear programming and optimizing, should be particularly mentioned. Here are the difficult problems, often of much greater payoff, in which much of the effort will be applied over the next several years.

GOVERNMENT APPLICATIONS

THE BUREAU OF CENSUS was one of the first to encourage large-scale computer development for its use. UNIVACS were used for part of the 1950 census analysis. Other typical applications have been Government bond records, social security, veterans' records, income tax, air traffic control, map making, letter sorting, patent search, statistics of all kinds, as well as corporation, sales, and other tax accounting. These are, of course, additional to the business and defense applications cited previously.

MISCELLANEOUS APPLICATIONS

Translation of languages. One of the truly monumental tasks, this is now in its infancy though one of vast social significance. Large random access, permanent memories are needed, permitting photographic and optical techniques. At present, teams of programmers and linguists are studying the linguistic rules and testing proposed translation algorithms by means of trial translator programs on general-purpose computers.

Retrieval of Information. Retrieval runs the gamut from searching classified information on chemical-formulas or United States patents to automatically abstracting books and articles. The latter involves character recognition and linguistic rules closely related to language translation for discovery of information content. Ingenious apparatus has already been developed for high-speed search and printing of abstracts, and engineering reference systems superior to pulling and printing a large drawing are being investigated.

Research with Computers. This is extending into many new areas: the study of dairy herd performance, medical, biological, geophysical, nuclear research, using planned experiments, analysis of variances, probability, and Monte Carlo techniques taking advantage of the high-speed and low-unit computing cost of the computers.

CONCLUSIONS—COMPUTERS AND AUTOMATION

COMPUTERS, meaning all that broad field of devices whose prime function is to process information as opposed to material, constitutes a large part of automation as it is known today. It constitutes practically all of office automation, all of the automation of man's mental and clerical work. It is the intelligence which, associated with the machines for his physical work and his defense, removes the human limitations of time and space, the limitations of human sensing and reaction, in man's reach into outer space and into the future. The computer and all of the associated equipment for the processing of information elevates man to a new level of accomplishment through automation.

For those things which he can conceive and knows how to do, he need no longer be limited by the computational obstacles or the detailed decision making. He can now program these things to be done by the computer under his general control. Instead of making each design himself, he can develop the techniques for making an excellent design, and from there on relegate the routine design job to the computer.

This field holds tremendous challenge and opportunity. The computer is to the machine, what education is to man. We now have the tools to educate our machines. Engineers have accepted this challenge and in the last 10 years have made tremendous progress. In this time, the vista of possibilities has been continually expanding. The next 25 years should see the fulfillment of the dream of automation that is in but its earliest stage today. Computer intelligence should by then be applied wisely throughout industry to handle all of those types of tasks better handled by machine. Far from displacing man from employment, this will elevate him to a world of greater effectiveness and greater opportunity, as has the harnessing of the forces of nature in providing his physical power and transportation.

Lighting for the Past 25 Years and the Future

W. F. LITTLE

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FELLOW AIEE

IN 1955, the lighting industry celebrated Light's Diamond Jubilee commemorating the invention of the incandescent filament lamp and the birth of electric utilities in the form of Edison Electric Illuminating Companies. A feature of this celebration was a 75-kw incandescent lamp constructed especially for this use, just as a 50-kw lamp had been made for exhibit at the New York World's Fair in 1939. This mammoth lamp, burned from time to time for demonstration during the celebration, should not be taken to indicate that advance in lighting has been solely in the size of the source.

INCANDESCENT SOURCES

WHEN AIEE celebrated its Golden Anniversary, most artificial light was produced by incandescent lamps, which then were produced at the rate of about 400 million a year. These lamps had filaments of coiled tungsten wire, but within a year it had been found that if these coiled filaments were again coiled, the efficiency of the filament as a light producer was increased by about 10%. Thus, the coiled-coil filament was born and a chain reaction of bulb-size reductions was touched off.

The first lamp to be redesigned for coiled-coil filament was the 60-watt lamp, in which the bulb size soon was reduced from A21 to A19.* This in turn was followed by the 100-watt, which was reduced in size from A23 to the A21 bulb, then by the 75-watt and the 150-watt, and in a short time the reduction in bulb size was extended to include the 200-watt size. As a result, lamps rated 25, 40, 50, 60, and 75 watts now are furnished in bulbs of the same diameter, A19, though the 25-watt lamp is ½ inch shorter and the 40-watt lamp is ⅜ inch shorter than the others. Thus, it is no longer possible to use bulb size as a means of limiting the power taken by lamps that may be inserted into a fixture.

When the coiled-coil filament was introduced, it meant that the finished filament was shortened so much that a new filament disposition was used. The earlier coiled filament was arranged in the form of a horseshoe or C, with the plane of the filament perpendicular to the axis of symmetry of the lamp, in the more commonly used general service lamps. With the introduction of the coiled-coil filament, the filament was arranged in a straight line, again perpendicular to the axis of symmetry of the lamp. Very recently, it has been found that a marked increase in efficiency can be obtained if the filament is disposed in a straight line along or parallel to the axis of symmetry. Today, lamps incorporating such arrangements are available in 500-, 750-, and 1,000-watt sizes, indicated as having CC-8 or 2CC-8 filaments. A 100-watt lamp incorporating this filament construction also has been announced, now in an A19 bulb.

Both the life of a lamp and the amount of light obtained from it are determined by the temperature of the filament. For a given lamp construction, the higher the filament temperature, the greater the efficiency (lumens per watt) and shorter the expected life. That is to say, life and light output are interdependent. It is possible to design lamps for very long life, but at the expense of efficiency. In general, lamps have been designed to give an economic balance between these two factors, with the intended service determining which should receive the greater consideration. Since it is recognized that there are service locations where longer life is more important than efficiency, extended-life lamps now are available.

An outstanding development in incandescent-filament lamps during this period has been that in automotive headlamps. Twenty-five years ago, those cars having electric headlamps were equipped with metal reflectors into which a small 21-21 or 32-32 candle-power bulb was inserted as the light source. The year 1937 saw the development of the sealed-beam unit, an all-glass headlamp incorporating the reflector, the filaments, and the lens in one hermetically sealed PAR unit, which appeared first on new cars in 1940. The lamp, rated in watts rather than candle power, had numerous advantages, though probably the most important was that this lamp, with built-in reflector, maintained its efficiency remarkably well during life due to condensation or blackening occurring principally at the lesser important parts of the assembly. More recently this lamp has undergone modifications to improve the beam produced, and in 1958 many new cars first appeared with the dual-headlamp system, two lamps replacing each headlamp as previously used.

The PAR lamp type was built into lamps for normal voltage use, the first being the 150-watt PAR38. Today PAR lamps are available in a range of ratings and bulb sizes, giving various beam patterns, spot and flood, in

* Lamp-bulb designations are comprised of letters and numbers, where the letters indicate shape and the numbers, the maximum bulb diameters in eighths of an inch.

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The authors acknowledge with thanks the contributions of photographs and information by representatives of various lamp manufacturers.

GE Photo

Early industrial installation when local lighting was considered sufficient.

GE Photo

Industrial lighting, showing a modern installation against a background installation that is not so modern.

hard glass which makes them suitable for outdoor use. Certain sizes also are available in side-prong bases so that the space required is greatly reduced. Parallel developments in PAR types have provided lamps for locomotive headlamps and airplane landing lights.

A somewhat similar development has taken place in R-bulb lamps, internal reflector lamps in blown-glass bulbs, with the result that both spot and flood beam-pattern lamps now are available in a range of sizes from the 30-watt R-20 to the 1,000-watt RB-52. A line of smaller, lower voltage lamps in R bulbs has been developed for interior lighting of airplanes.

Among the special lamps developed for aviation use is a miniature lamp with a filament capable of withstanding forces of 100 g, for use in providing light on the rotor tips of helicopters.

For many years, frosting of the bulb, more recently inside frosting, has been the principal means of obtaining some diffusion and hiding of the hot filament in incandescent lamps. About 1948, the use of an inside coating of white silica first appeared. This coating absorbs about 2% of the light, but provides a greater degree of diffusion and lower brightness than was obtainable with frosting. Lamps with this coating are available in certain types for use in floor and table lamps and very recently have been announced in lamps having newly developed bulb contours.

Twenty-five years ago only a few projection-lamp types were available for movie or slide projectors used by schools, churches, and similar groups. Today, there are over 200 projection-lamp types, many used in 8-mm movie and 35-mm slide projectors by amateurs. Lamps now are only about ¼ the physical size of 25 years ago and operate at higher efficiencies for the same life. In certain lamps, only recently available, a mirror within the bulb makes it possible to eliminate the external mirror (and in some cases the condensing lens) from the 8-mm projector and still get more light on the screen than was previously possible.

Marked development has taken place in lamps for use as infrared sources for drying and other heat applications. These principally are lamps operated at lower filament temperatures where the production of light is not an objective. A line of heat lamps in R bulbs followed the development of that bulb. More recently, a line of tubular quartz lamps capable of dissipating 100 watts per inch of length has made possible heat sources rated up to 5,000 watts. One specialized development of heat lamps in the R bulb was 500- and 750-watt lamps for use as cooking elements on electric ranges.

Many other developments in incandescent lamps include the "grain of wheat" lamp (the smallest lamp made), prefocused flashlight lamps, silvered bowl and semisilvered bowl lamps, 3-way lamps for use in portable lamps, and the "bug lamp" producing yellow light found least attractive to bugs. These and many more too numerous to mention have appeared, in spite of several years during which new product development was limited to lamps for use by the armed forces.

METALLIC-VAPOR SOURCES

Previous to 1935 metallic-vapor sources in the form of sodium-vapor lamps and mercury-vapor lamps were commercially available and had had their chief application in street lighting and industrial lighting. Probably the earliest was the Cooper-Hewitt low-pressure mercury lamp which found fairly wide industrial use. The advent of the 400-watt high-intensity mercury lamp brought in the high-pressure mercury source and provided a compact high-efficiency lamp of high light output, originally 14,000 lumens, now 21,000 lumens. Although the compact nature of this source made for ready control of light distribution, the distinctive color of the light limited its application.

Again, the distinctive color of the sodium-vapor lamp, practically spectrally pure yellow, limited the application of this lamp in spite of claims of marked improvement of visual acuity. However, development of sodium lamps continued and lamps were offered

in several types and sizes. The claims of added acuity, however, were not wholly substantiated, and the requirements for accessories such as the complex operating circuit and the vacuum-flask enclosure to maintain lamp-operating temperature combined to inhibit application of this lamp, with the result that today its use in this country is more or less limited to the lighting of danger points on highways where the color alerts the driver to changed conditions.

The high-intensity mercury lamp, on the other hand, has continued to grow in application and in development. The use of the quartz arc tube has provided a lamp that can be operated in any position without additional auxiliary equipment. Ballasts have been made available to operate lamps either singly or, in some cases, with two lamps on a lead-lag circuit. This family of lamps ranges over sizes from 100 to 1,000 watts and now is available in clear glass envelopes, as color-corrected lamps with a fluorescent phosphor on the enclosing bulb and in various types of reflector lamps. The most recent color-corrected types carry such designations as "white," "silver white," etc. The most common bulb shape for these lamps other than some of the reflector lamps now is the so-called BT bulb. Lamps of this general type likewise have been developed to operate directly on 6.6-ampere series circuits.

Quite early, a mercury lamp was developed with an incandescent-filament ballast located within the enclosing bulb. Lamps incorporating this construction now are available in this country in 450- and 750-watt sizes.

Development likewise has taken place in mercury lamps in tubular bulbs. One line of low-pressure lamps is made in bulbs which transmit ultraviolet and find application as "germicidal" and "bactericidal" lamps for germ or bacteria control. Others have been developed for photochemical uses. Still others have been brought out as light sources in sizes ranging up to 3 kw, with one of the most recent being a 1,500-watt lamp rated at 81,000 lumens.

GE Photo

View of new street-lighting installation showing unusual pole design, each pole mounting four fluorescent luminaires. One luminaire is parallel to the sidewalk, two are mounted over the street at upward angles of 20 degrees, and the fourth is mounted in the normal over-the-street position.

Another development has been the RS sun lamp to provide erythemic radiation in a self-ballasting lamp to operate in the usual medium-screw lampholder.

FLUORESCENT SOURCES

PROBABLY the most spectacular advances have been made in the field of fluorescent lamps, where full commercial development has taken place within these last 25 years. Whereas none of these lamps were commercially available in 1934, lamps of this type now produce most of the light energy that is being generated in this country.

The lamps consist of an enclosing bulb, coated on the inside with a fluorescent phosphor which is activated by the ultraviolet produced by an electric discharge through low-pressure mercury vapor either from cold cathodes or hot cathodes. The light output is determined principally by the phosphor, though mercury lines in the visible spectrum are transmitted through the phosphor and the glass bulb. Light may be produced efficiently in many colors under this arrangement, but daylight, cool white, white, and warm white have represented the major volume, now supplemented by deluxe cool white and deluxe warm white where color rendition is of importance.

The early hot-cathode lamps were rated at 15, 20, and 30 watts and were started from preheated cathodes by an electromagnetic starter switch. This starter was replaced by the glow-switch starter, which later was modified to provide a cutout to disconnect the lamp

GE Photo

Experimental 1,000-foot-candle installation in a model-making shop area, using 1,500-ma fluorescent lamps in aluminum reflectors. Louvers of wedge-shaped cross section provide 45-degree shielding.

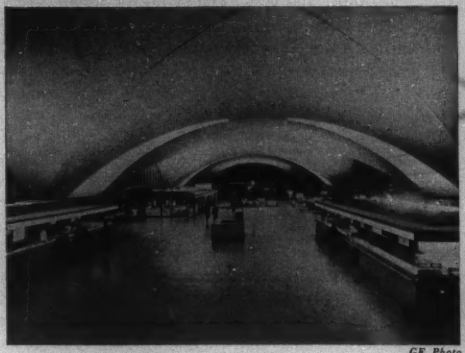
after failure to start within a reasonable time. Within two years this line was augmented by the 40-watt and then the 6-, 14-, and 100-watt lamps. Cold-cathode lamps appeared in several lengths and current ratings.

Following closely after the war, the instant-starting hot-cathode lamp was developed in which high voltage served to start the lamp without benefit of an auxiliary starter. This led into the slimline lamp type, with a single pin at each lamp end replacing the earlier bipin base.

Since these are a form of electric discharge lamp, a ballast is required for stable operation. Early ballasts took the form of simple choke coils for a-c operation or resistors for d-c operation. Because of inherently low power factor of the lamp and choke combination and to assist in correcting for stroboscopic action by these early lamps, the 2-lamp ballast was developed in which one lamp is ballasted by a choke and the other by a near-resonant combination of choke and capacitor. The 2-lamp ballast, known as the lead-lag ballast, operates the two lamps out of phase to correct the stroboscopic action, and at the same time gives power-factor correction.

Later, with improved phosphors that have a greater decay time, it was possible to operate lamps in phase without undue disturbance caused by cyclic light variation. Under this condition and with added economic pressure resulting from ballast costs, the series-sequence ballast was developed for the slimline lamp. In this ballast, two lamps are started in sequence and then operated in series from a single-ballast circuit. An appreciable saving in materials and in ballast losses is realized.

During the first 12 to 14 years of fluorescent lamp application, it was possible to dim only lamps of the cold-cathode variety. Hot-cathode lamps, up until 1952, were of types that suffered loss of life when operated in dimming circuits. However, at that time, announcement was made of the rapid-starting type of lamp, in which the cathodes are continuously heated by separate heater windings or transformers. These lamps may be operated in dimming circuits without loss of life as long as the cathodes are properly heated.



GE Photo

Lighting in a modern public building, shown is view of St. Louis Municipal Airport lobby.

Following the advent of the rapid-starting lamp, other RS lamps have been developed to operate at loadings well above the then conventional 425 milliamperes. Lamps of this type now are available operating at 800, 1,000 and 1,500 milliamperes. These lamps are available in lengths of 2, 4, 6, and 8 feet, except for the 1,000-milliampere lamp which is made only in the 6-foot length.

Improvements in the phosphors used in these lamps have eliminated the highly toxic powders originally used and have resulted in appreciable increases in lamp efficiency. Improvements in cathode construction have been mainly responsible for raising guaranteed life from 2,500 hours to 7,500 hours. As in other lamp fields, many variants have been included such as circular lamps (with the tubing bent into circular form), hairpin lamps, reflector lamps, and sun lamps.

Westinghouse Photo

Typical store lighting showing use of recessed fluorescent units for general illumination and incandescent downlights in gimbals for accent.

MISCELLANEOUS SOURCES

IT WOULD BE most remiss if this review were limited to the aforementioned advances in light sources, since there have been many new developments in other fields. For instance, the carbon arc, which predates even the filament lamp, has continued to be developed for many applications such as moving-picture projectors, high-intensity searchlights, and other uses requiring a small source of extremely high brightness. Such improvements have resulted in increased brightness and, in certain instances, in increased life.

Another new source, in some ways competing with the carbon arc, is the so-called short-arc or compact-arc lamp, using argon–mercury, xenon–mercury, or xenon in essentially spherical bulbs of clear fused quartz, with

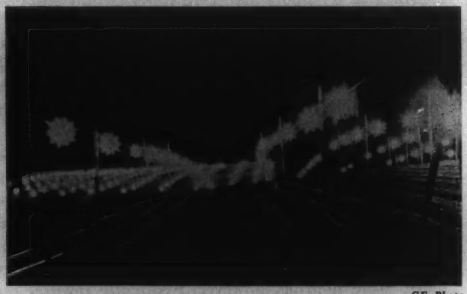
diametrically opposite current-carrying seals. In general, the arc length ranges from a fraction of a millimeter to 1.0 centimeter. Like other discharge lamps, these require auxiliary devices to start and ballast the arc. They are designed primarily for searchlight, projection, optical, and photographic service.

Another development in gaseous discharge lamps has been in the field of flash tubes giving an extremely intense flash of only microseconds duration. Such lamps found wide use in military photography during the war and also in commercial and amateur photography where they eliminate replacing the lamp after each flash. Another application has been in airport-landing and aircraft-warning lights.

At the same time, new photoflash lamps, smaller in size and of increased light output, have appeared. In some of these, a chemical deposit on the lead wires has replaced the earlier foil or shredded-foil filled types, while more recently the use of zirconium has made higher light output possible. The most recent addition has been a lamp without the conventional metal base. More than a million of these lamps are used each day for photographic purposes. An infrared photoflash lamp was developed for military use.

A fairly recent light source, still under intensive development, is the electroluminescent cell. This is essentially a capacitor, with one transparent plate, where light is developed in the dielectric which incorporates a phosphor. Up to this time, brightnesses obtained in this manner have been low in comparison to other sources. Performance, in general, has been better at frequencies above normal power frequencies.

Considerable work has been done on the operation of electric discharge lamps, particularly fluorescent lamps, on circuits at higher frequencies. Several sizable



GE Photo

Controlled plant growth by artificial lighting.

installations have been made at 360, 400, and 840 cycles per second. Such operation greatly reduces the size of the ballast required, but necessitates the use of a converter or some similar source of the higher frequency.

Among other developments, there is a lamp operated at radio frequency, having a very small source dimension which makes it suitable for film printing and projection. Another interesting item is a submidget

Westinghouse Photo

Example of modern residence lighting using fluorescent valance and table lamps.

glow lamp, with source dimensions only 0.03 by 0.04 inch, developed for recorder use in missile work.

OTHER DEVELOPMENTS

Associated with lamp developments have been advances in measuring instruments and codes and standards for the application of light. The barrier-layer photocell has been the basis for several new instruments for measuring lighting intensities. This photocell, used in a current balance circuit, likewise has been the basis for automation of photometry. Within the last year two equipments have been described for the automatic testing of lighting units, with data appearing as punched tape or punched cards which can then be processed on computing machines, to obtain full operating characteristics of the unit under test.

During this time, a new code has been written for street-lighting installations, and new recommendations adopted for school, office, and store lighting. In addition, a new method of calculating coefficients of utilization has been approved and put into use, improving the accuracy of predicting the illumination level to be expected from an installation of fixtures of known characteristics.

From time to time over the years, as higher illumination levels became practicable, new recommendations have been made for lighting levels for various kinds of work. As the result of an extensive investigation of factors affecting vision and the ability to see and read, the Illuminating Engineering Society, in 1958, again revised upward its recommended lighting levels for various tasks. While these new recommended practices call for marked increases, in certain cases, it is felt that they still are within the range of values obtainable from present-day lighting equipment.

As lamps have increased in numbers of sizes, types, and varieties, it has become increasingly more complex to describe a lamp required for a particular application or for replacement of a lamp burned out in service. In an effort to ease this situation and to provide

a common description for the same lamp regardless of source, lamp manufacturers recently have accepted codes serving to identify various photographic (projection) lamps and high-intensity mercury lamps. This project is administered by the American Standards Association.

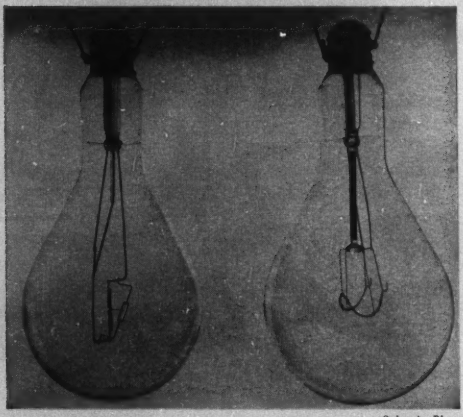
APPLICATIONS

JUST ABOUT THE TIME that AIEE celebrated its 50th Anniversary, the first major-league baseball park was floodlighted for night games. Since that time, night sports have become so common that not only are all types of major sports events put on at night, but also many high school athletic fields are floodlighted. Incandescent lamps are most commonly used for this service, frequently operated at overvoltage in order to get the desired high intensities on the playing field.

The two world's fairs, one at San Francisco and the other at New York, spelled a new high in both floodlighting and display lighting. The New York World's Fair was the proving ground for the development of the fluorescent lamp. New light sources, new luminaires, and new engineering make for even greater heights in this line of work.

Rather promptly after the announcement of the fluorescent lamp, the 20th Century Limited was lighted with lamps of this type. Today most Pullman car lighting is accomplished with fluorescent lamps, and many cars of other types are so lighted.

High-intensity mercury lamps now are widely used in the lighting of interchanges for turnpike or toll roads and, in many instances, long stretches of urban and interurban pikes and throughways are lighted continuously with these lamps, or fluorescent lamps, with yellow lights marking entrances and exits. Color-corrected lamps find use in urban applications. The 1,000-milliampere fluorescent lamp was developed especially for street lighting, and the use of these lamps has meant a decided boost in illumination levels for metropolitan districts. Special asymmetric luminaires are constructed, many for angle mounting, to confine much of the light to street surfaces.



Sylvania Photo

Large general-purpose incandescent lamps show filament constructions. Burned base up, the axial-filament lamp gives less bulb-blackening and higher efficiency.

The stations of New York City subways now are in process of being relighted with fluorescent lamps. The newer subway cars likewise are lighted with these lamps.

Industrial lighting continues to use incandescent, fluorescent, and mercury sources depending upon the area to be lighted and the kind of work being carried on. Where high lighting levels are desired, fluorescent is the most common source. High-bay areas use mercury or incandescent. Little attention previously was given to lighted ceilings. Now, however, the desirability of good general lighting in factory work spaces, including ceilings, is considered a must. With the much higher light levels on the work, a well-lighted ceiling keeps the surrounding brightness within a comfortable range. In 1935 a general lighting level of 10 to 15 foot-candles was considered adequate. Today illumination levels of 100 foot-candles or more are becoming common and, where very exacting work is to be done, intensities as high as 1,000 foot-candles are being used experimentally.

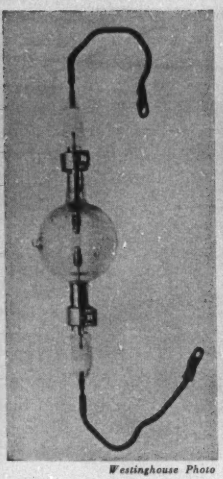
Commercial lighting equipment has undergone quite a change during the last 25 years. At the start of this period, space requirements were not critical, ceilings were high, and most lighting units were hung from ceilings on chains or stems. As the years have passed, space requirements have become critical, ceilings in general are much lower and a large percentage of present-day lighting equipment is made to mount near the ceiling, flat against the ceiling, or recessed into the ceiling, and in certain instances the ceiling itself has become the "source" of light. This trend has called for new concepts in fixture design and new materials for light control. It also has posed temperature problems both for the ceiling on which a fixture may be mounted and for the equipment that goes into the fixture, i.e., lamps and ballasts.

Stores and offices are using all of the fixture types previously mentioned together with incandescent downlights so located as to provide high local illumination or to give accent to goods being displayed. In general, office lighting now tends toward higher levels of illumination, with low contrast and a minimum of reflected glare. Store lighting, however, frequently reverses certain of these trends, where high contrasts and even glare may be used to draw attention to merchandise on display.

Relatively few fixtures now use plated reflectors; aluminum, anodic-processed to give permanence, has taken over, especially where specular reflecting parts are used. Both glass and plastic are being used for lenses and diffusers. In many cases, the lenses for recessed units are so made that no part extends below ceiling level. Lens designs have been made to limit

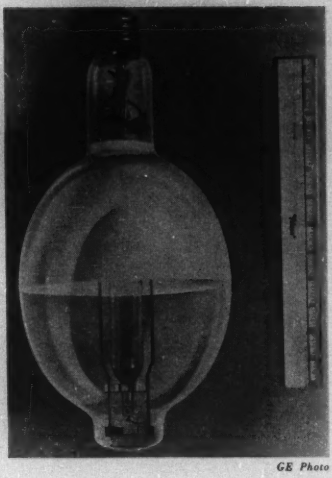
GE Photo

New "All-Glass" flashbulb, compared in this photograph with an ordinary paper clip, is said to be the world's smallest.



Westinghouse Photo

Short- or compact-arc lamp developed for uses requiring concentrated bright source.



GE Photo

Newly developed improved-color reflector-type 1,000-watt mercury lamp in BT bulb. Phosphor reflector directs two thirds of light downward.

brightness within normal viewing angles. Egg-crate louvers, in metal or plastic, find wide application in fluorescent fixtures in order to hide the lamps from direct view.

Twenty-five years ago a schoolroom lighted to 10 foot-candles was considered to be well illuminated. Present recommendations would raise this level to 70 foot-candles to provide ample light for pupils to see when writing with pencil on paper or reading some of the duplicated material used in teaching. Much attention now is given by school architects to seating arrangements and other means of using light effectively.

The level of general lighting in the home was scarcely 3 foot-candles 25 years ago, with a maximum of 20 foot-candles where fine work was to be done. At the present time, the recommended values are 10 foot-candles of general illumination and 30 to 70 foot-candles for reading or sewing. These higher lighting levels are accomplished through the use of "built in" cornice, valance, or torchere lighting, with added table or floor lamps. The most effective table and floor lamps are designed to throw the majority of light downward through diffusing units of low brightness and large area, thus retaining the illuminating quality and reducing the reflected glare to a minimum. Typical examples of recent lighting installations are shown in the accompanying illustrations.

WHAT OF THE FUTURE?

In rooms provided with 150 foot-candles or more of fluorescent lighting, the wintertime heating requirements are fulfilled to an appreciable extent by the power dissipated by the lighting equipment. With higher illumination levels to come, this will be an increasing factor.

Studies under way will show methods for carrying heat from the luminaires directly outdoors, so that heat produced by lighting equipment will not be a serious additional load on summertime air-conditioning capacity.

Reduction of the ambient temperature surrounding indoor fluorescent lamps will result in operation of the lamps themselves at bulb temperatures closer to the optimum for highest light output.

Provision for air-conditioning ducts, together with economics in the cubic-foot content of buildings is forcing a trend toward lower ceilings. Developments in lighting systems and luminaires will come which will do a more satisfactory job of lighting with sources close to the ceiling.

Electroluminescence may lie in the category of luxury lighting for entire rooms, although a major technological breakthrough would alter the picture entirely. Such systems would bring about wholly new concepts in the wiring of rooms.

Substantially elevated lighting levels will continue to direct increasing emphasis on more potent light sources, particularly of the discharge (fluorescent) types

Some go so far as to predict that more compact fluorescent light sources that can be screwed into a lampholder like an incandescent lamp will be forthcoming. This will mean the elimination of ballasts as we now know them. The development of more efficient means of generating ultraviolet radiation or the use of radioactive materials may help toward this end.

Lamps of all types which incorporate greater degrees of light control will become available.

There is no likelihood that a metal better than tungsten will appear suitable for filament lamps. The latter will remain popular because of its simplicity of use and ease of accurate light control.

Phosphor behavior in fluorescent lamps will be better understood every year. Lamps that depreciate less with burning, so that lowered efficiency late in life will not act as a penalty on long life, will be forthcoming.

Tung-Sol Photo

Cutaway views of automobile headlamps showing internal construction for the dual system.

Developments to make lamp starting easier without impairment of useful life will make fluorescent lamps adaptable to many uses where very frequent starting now makes them of doubtful economy.

The use of radiant energy to influence plant growth is probably going to develop far beyond present applications. Complete control of blooming time, deactivation of plant pests, control of weed seed germinations, and any phase of plant growth affected by a light cycle, may be expected.

Experiments now going on suggest that an underground community, supplied with sufficient power, will be able to subsist entirely independent of daylight.

Advances in engineering and manufacturing techniques will continue to make photographic light sources smaller, more efficient, and more convenient to use.

Light will surely play an ever-increasing part in enhancing the everyday environment, complementing the current heightened appreciation for style and color with a better and wider understanding of the use of colored sources.

More complete understanding between architects and lighting consultants will mean that forms will be created and revealed as never before, so that the concept of the designer can be carried out in the actual structure, as well as on paper.

The thin concrete structures now attracting so much attention will demand entirely new approaches in lighting, inasmuch as there is rarely a niche or cavity in which to conceal lights. Architectural forms will evolve in which provision for lighting is a controlling force.

Proofs that lighting levels far beyond the present average in office, store, factory, home, and school can be employed profitably will need to be intensively explained. Lighting specialists will need to inform themselves to teach the users of light the values that better lighting will return to them.

Increased appreciation for the economic value of improved lighting will be one of the features of future promotion. The return for the investment in lighting, in terms of production and other dollar values, is a provable factor.

Twenty-five years from now, the 200-foot-candle installation will probably be commonplace, and surely there will be many of 1,000 foot-candles. But these installations still will have to be designed with visual comfort in mind.

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Twenty-Five Years of Progress in Aircraft Electrical Systems

View of DC-3—cruising speed 185 mph, 21 passengers, 1935 transport. Douglas Aircraft Company photo.

TWENTY-FIVE years of aviation history accounts for approximately half the time since the Wright Brothers made their famous flight at Kitty Hawk. In the time period since the Golden Anniversary of the AIEE, 1934, great advancements and major breakthroughs have been made in the field of aviation.

Especially noticeable is the tremendous progress made in the application of electricity in aviation. The advancement of electrical generation and components in electric systems, which, prior to 1934, were somewhat obscure in scope as well as importance, has had its effect on the whole electrical industry. In today's era of jet propulsion, electrics and electronics play roles equal in importance with structural integrity and propulsion.

By 1934, the art of electric generation in airplanes had advanced somewhat beyond the small wind-driven generators found on World War I airplanes, but the advance was not great. Briefly, the U. S. War Department, Air Service, initiated development of engine driven d-c generators in the early 1920's. These machines, the largest having a 50-ampere capacity at 15 volts, weighed approximately 35 pounds. The low weight per watt ratio of 0.047-pound per watt was considered to be a real engineering accomplishment at the time. This size machine resulting from this development was sufficient to supply the needs of commercial and military airplanes into the middle 1930's.

In 1935, the first of the famous Douglas *DC-3* commercial transports was flying and had an installed generator capacity of 1.5 kw which soon grew to 3.0 kw on 1938 models, because of increased loads and demands on the system. This system, generating power at 15 volts d-c, was fairly representative of all airplanes operating in that era.

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The author extends his appreciation for the co-operation and contributions of many AIEE members engaged in aviation and to C. R. Moore of Douglas Aircraft Company for his help in preparing this article.

MILITARY NEED SPURS GROWTH

IN THE LATTER HALF of the 1930's, because of international conditions, development of military aircraft began to accelerate rapidly. With the advent of large four-engine bombers and transports, electricity in aircraft graduated from relative unimportance to a position of one upon which the mission of the airplane depended. The demand for power was so large, a higher voltage system was required. Several different voltages, both a-c and d-c were considered. The *XB-19*, developed and built by Douglas for the Air Force, which was the largest land-based airplane of its time, had a basic 120-volt 400-cycle 3-phase a-c system supplied by two auxiliary gas-engine-driven 12.5-kva generators. Prior to the *XB-19* the first experimental *DC-4* had a 120-volt 800-cycle single-phase a-c system supplied also by auxiliary gas-driven generators. However, for a number of reasons, the early a-c system installations were premature. Utilization equipment which would accept a-c was not readily available. The advantage of using the main engines as prime movers for paralleled a-c generators was not possible because a suitable transmission to produce a constant output speed from variable input speeds had not yet been developed.

Finally, a decision was made to standardize on a 28-volt d-c system. A group of generators with this voltage and ratings up to 100 amperes output were developed. The Boeing *B-17*, a four-engine bomber built in the late 1930's was originally equipped with four 100-ampere, 28-volt, d-c generators, one on each engine, connected to a common bus, plus a 24-volt battery. Even this capacity was not sufficient. As a result, 200-ampere

generators were developed and installed on service as well as production airplanes. The electrical loads on the *B-17* which prompted the development of higher capacity machines consisted in part of engine starters, landing gear actuators, fuel and hydraulic pumps, gun turrets, control surface actuators, communication and navigation equipment, lighting, and instrumentation. One load, not large but extremely important, was heated clothing for the use of the crew members in sustained high-altitude combat flight.

The problems of the *B-17* electrical system were rather typical for all military airplanes prior to World War II in that loads were growing faster than available generating capacity. The availability of 200-ampere generators seemed to bring the situation under control. However, the brushes on these new high-current generators wore down rapidly at altitudes of 25,000 feet or higher, presenting a new problem.

A program to find a solution resulted first in a brush which had satisfactory life at high altitude but was not satisfactory at low altitudes. It was not too long afterward that a compromise solution resulted in satisfactory brushes for all altitudes.

Meanwhile, a program had been started for the development of a rectified a-c system. Actually, the U.S. Navy had already made some progress along these lines. As a result, rectified a-c systems with an output per generator of 200 amperes at 30-volts d-c were developed and successfully flight tested. These systems were somewhat heavier than d-c generator systems of the same capacity and because of the size of the rectifiers would probably have been rather vulnerable to enemy gun fire.

At the start of World War II, design and development of commercial aircraft stopped. However, during this period, great advancements in electrical equipment to meet combat requirements were made. New bombing equipment, autopilots, electric gun turrets with amplidyne control, radio and navigation equipment, electrically driven instruments, propellers, and many other electrically operated equipments such as relays, actuators, switches, and automatic controls were developed.

One of the most significant and successful developments, of which many modern versions are in use today, was the carbon-pile type voltage regulator. This regulator was the answer for better regulated systems and the problems of environment with which prior regulators were plagued.

Early in 1943, the Boeing *B-29* was put into flight test. This bomber was developed to meet the requirements of the Pacific Theater, namely, higher altitude, longer range, greater payload, and higher speed. The electric loads went way up, requiring the development of 300-ampere generators, which became available in 1944. Prior to this, six 200-ampere generators were used. This airplane was the most extensively electrified airplane of its time and did much to prove the feasibility and reliability of electricity as a secondary power medium in aircraft. In addition to the six main engine-driven generators, a 175-ampere 30-volt gas-engine-driven auxiliary power unit was a permanent installation in the *B-29*.

Not all of the increasing electric loads on aircraft could be operated directly from a 30-volt d-c power source. Some loads required a-c, some 26-volts single-phase, and others 115 volts single-phase and 3-phase. To service these loads, a line of inverters was developed, eventually ranging in capacity up to about 3,000 volt-amperes. These were rotating units—a 28-volt d-c motor driving an a-c generator. They were voltage and frequency controlled, maintaining a frequency in the vicinity of 400 cycles. The first such units did well to maintain frequency within the specification limits of 380 to 420 cycles. Modern inverters control speed much better—more in the order of plus or minus two or three cycles. Most of the rotating units operate at either 8,000 or 12,000 rpm so, along with the required a-c, they

Courtesy Douglas Aircraft Company

View of DC-8—cruising speed 586 miles per hour, 144 passengers. 1959 transport.

generate plenty of noise. Noise reduction is but one of the benefits to be realized with the static inverters now becoming available.

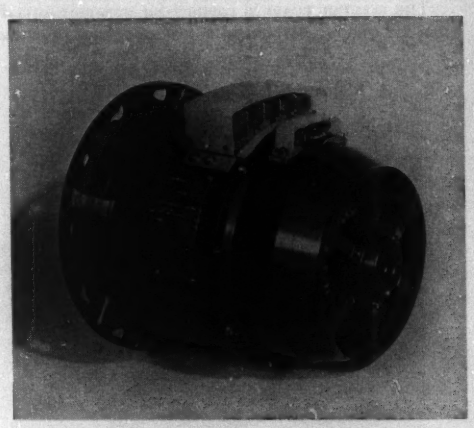
At the start of the war, it had to be assumed that it might not go as well for us as planned; therefore, design work was started on airplanes having even greater range and higher performance than the *B-29*. One of these was the Convair *B-36*. The preliminary load analysis showed that the electric loads on this airplane would be too high to consider supplying them from a basic 30-volt d-c generating system. A higher voltage would have to be employed.

D-C VS A-C VOLTAGE SYSTEMS

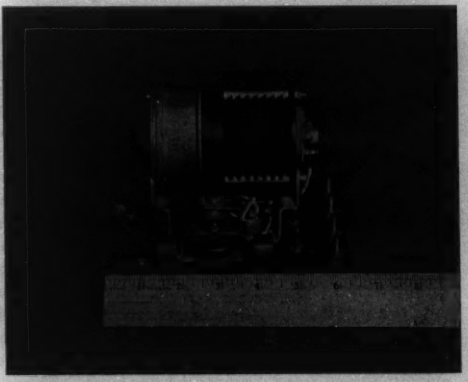
TIME DID NOT PERMIT an exhaustive leisurely analysis of the problem. Nevertheless, both d-c and a-c voltage systems were studied, and for various reasons the basic system selected had the following characteristics: 120/208 volts 3-phase 400 cycles constant frequency, with an installed generating capacity of four 40-kva generators. Transformer–rectifiers were used to supply such 28-volt d-c loads as could not be converted to a-c. As may be realized, the problems to be solved were many and tough, particularly in view of the time schedule established for the airplane to become operational. Inasmuch as the system had to maintain constant frequency with provision to parallel all four generators, and since the main engines were to be used as prime movers, one of the more difficult problems was to produce a satisfactory variable-speed input, constant-speed output drive. A number of designs were proposed, and some false starts were made. Finally, a prototype hydromechanical transmission was produced which, although still not all that could be desired, showed definite promise. Effort was concentrated on this transmission, and ultimately a usable unit became available. Initially, it had many shortcomings but considering the relatively short time allowed for development, and also the pressure on all industry for development of many other items urgently needed for the war effort, this transmission was a remarkable achievement. This transmission, modified many times and greatly improved, is the one most generally used in aircraft today. The war ended before the *B-36* became operational but it became an important airplane for the Strategic Air Command. The *B-36* did a great deal to advance the state of the art of electricity in aircraft.

During the war, there was no commercial aircraft production, but many of the advances in electric systems and equipment were, with minor changes, applicable to commercial transports. Not long after the end of the war several new commercial airplanes were placed in operation. These included the Lockheed *Constellation*, Douglas *DC-6*, Boeing *377*, Martin *202*, and Convair *240*. All of these airplanes had 28-volt d-c basic electric systems which, except for installed generator capacity, were pretty much alike. Some had small variable-frequency engine-driven a-c generators installed to serve as emergency power sources for the a-c instrument loads. The Boeing *377* had the largest installed gen-

Type P1 200-ampere 28-volt d-c generator. Used extensively in World War II military airplanes. Weight: 44 pounds.



View of 30-kva 120/208-volt 3-phase 400-cycle brushless generator with integral exciter. Used in present-day jet transports. Weight: 76 pounds.



Carbon pile voltage regulator for control of 28-volt d-c generators.

erator capacity: six 300-ampere 30-volt engine-driven generators plus two 11-kva 3-phase 120/208-volt variable frequency generators, also engine-driven.

The Douglas *DC-6* and the Lockheed *Constellation* each had four 300-ampere 30-volt generators. The Convair *240* and Martin *202* being two-engine airplanes had two such generators. Except for increasing the capacity of the d-c generators to 400 amperes and upgrading the quality of the components used, the basic generating systems have not changed appreciably in succeeding models of these airplanes. Inverters have increased in size, and in some instances numbers, because the a-c loads have increased. Now most airplanes have two 2,500 or 3,000 volt-ampere inverters and some have 3 such units.

Hydromechanical generator drive transmission. Develops constant-output speed with variable-input speeds.

ELECTRIC LOADS IN COMMERCIAL AIRCRAFT

THE ELECTRIC LOADS in commercial transport aircraft may be roughly divided into two categories: essential and nonessential. The essential loads are those that are needed for proper operation of the airplane. Deicing and anti-icing, fuel and hydraulic pumps, communication and navigation equipment, instruments, certain lights, control surface actuators, landing gear actuators, etc., are in the essential category. Most of the cabin lighting, galley heating, most of the air conditioning, etc., are in the nonessential category. They are referred to as passenger comfort items. Loads in both categories have grown rapidly in the past 10 years and continue to grow. There are several reasons for such growth. The airplane may be viewed as a community. As it grows larger, the scope of operation widens and it takes more electric power to service the community. The essential loads continue to grow both in magnitude and scope because there is never any compromise with operational reliability. As more effective means of communication and navigation become available, they are incorporated into the airplane. An example of this is the weather radar. Many of the loads of this nature do not represent a large increase in power demand, but the increase in the number of "black boxes" is considerable.

Transistor-type voltage regulator for control of 60-kva 120/208 3-phase 400-cycle generators.

The nonessential, or passenger comfort, loads have undergone a considerable increase in magnitude. In the old days, a 500-watt coffee warmer, so that a cup of hot coffee could be served with the cold sandwiches, was sufficient. The galley loads on present-day airplanes equipped with 28-volt d-c systems run up to, and in some instances over, 10 kw. Some of the new jet transports have 29-kw galleys. Perhaps passenger comfort loads have grown as they have because passenger transportation is a highly competitive business. The airlines compete not only with each other but with all forms of land and sea carriers.

The *B-36* was the last of the large long-range propeller-driven bombers. The next large bomber to appear was the *B-47* which was equipped with turbo-jet

Differential-voltage reverse-current relay for use with 400-ampere 28-volt d-c generators.

engines. The electric loads were of such magnitude that on the first production airplanes the installed generator capacity was six 400-ampere 30-volt d-c generators plus two 20-kva 120-volt single-phase variable-frequency generators. The d-c generators served a dual purpose—they are also used as engine starters and so were called starter–generators.

During the late 1940's, design was started on a successor to the *B-36* and early in the 1950's it became operational. This was the *B-52*. It is equipped with eight turbo-jet engines and has very high performance characteristics. As usual, the electric loads on this airplane are high. Originally, the installed generating capacity was four 60-kva 120/208-volt 3-phase 400-cycle constant-frequency a-c generators. They were air-turbine driven, using main engine turbine bleed air. In some later models of the *B-52*, four 40-kva generators are driven directly by shaft power from the main engine turbines through a hydromechanical constant-speed transmission. The *B-52* is currently operational.

Control unit for 60-kva 120/208-volt 3-phase 400-cycle generators.

Up to the present time, nearly all aircraft generators have been air cooled, using ram air pressure. There are a few exceptions. One a-c generator that had limited application in a missile was cooled by intermittently injecting a small amount of water into it. This is called an evaporative cooled machine, and is described by the designers as a thermal lag device with greater thermal capacity obtained by the use of the latent heat of vaporization of the coolant. Machines of this type with capacity of 15 and 30 kva were produced.

Liquid cooling of generators is being accomplished to good advantage in some special applications. An airplane with very high performance characteristics, the *B-58*, has recently become operational. There is little detailed information regarding it available for publication, but it is common knowledge that it is equipped with 40-kva liquid-cooled a-c generators in which there are no brushes.

NEEDS OF TURBO- AND PROP-JET TRANSPORTS

A NEW GENERATION of commercial transport airplanes has just now come into being. They are the turbo-jet and prop-jet airplanes. The Douglas *DC-8*, Boeing *707* series, and the Convair *880* and *600* are all turbo-jet powered. The Lockheed *Electra* is equipped with prop-jet engines. The electric loads on all of these airplanes are considerably higher than on any previous commercial airplane. Because of this, the manufacturers have had to install what is to the commercial operators a new basic electric system. All are 120/208-volt 3 phase 4-wire a-c. The generators are Y-connected with the neutral attached to basic airplane structure.

Line circuit breaker, 3-pole 175 amperes 120/208 volts. Used in output circuit of 60-kva a-c generators.

The first of the commercial jet transports to go into service, the Boeing *707*, has, depending upon customer requirements, an installed generator capacity of 120 or 160 kva. This is provided by four 30-kva or four 40-kva 400-cycle constant-frequency generators driven from the main engines through hydromechanical constant-speed transmissions. In the Douglas *DC-8* the electrical system is comprised of four 20-kva generators for some customers and four 30-kva generators for others. They also operate at 400-cycle constant frequency and are driven from the main engines through constant-speed transmissions that are similar to those on the *707* airplanes. The Convair *880* and *600* airplanes are equipped with four 40-kva 400-cycle constant-frequency generators driven from the main engines through hydromechanical constant-speed transmissions which operate on the same basic principle as those on the *DC-8* and *707* but are produced by a different manufacturer. The generating systems on the *DC-8*, *707*, *880*, and *600* are designed for parallel generator operation. They may, however, be operated unparalleled if desired. The Lockheed *Electra* airplanes are equipped with four 60-kva generators. They also are driven from the main engines but not through a constant speed transmission. Therefore, they operate at variable frequency and cannot be paralleled. For flight operation, the prop-jet engines used on the *Electra* normally operate over a very narrow speed range—about 13,200 to 13,800 rpm. Thus, the generator frequency in flight is normally held close to 400 cycles. It is this feature of the engines that permits deletion of the constant-speed transmission. To re-

duce the noise level during ground operation, the engine speed is reduced to about 10,000 rpm. For such operation, one generator is driven through a 2-speed gear box which shifts automatically and permits generator frequency to be maintained at about 400 cycles, whether at ground idle or in flight. When the engine is operating at 10,000 rpm, all load buses in the airplane may be connected to this generator. The other three generators are disconnected from the transfer system by frequency relays in the generator controls.

VOLTAGE REGULATION

AT PRESENT, voltage regulation for most aircraft a-c generator installations is accomplished by the use of magnetic amplifier type regulators. Transistorized voltage regulators have been developed and successfully tested. They appear to operate at least equally as well as the magamp type and at a considerable weight reduction. So it seems quite probable that they will be used more generally in the future. Excitation power is obtained from either an integral exciter or by rectifying a portion of the a-c generator output. The latter method is referred to as static excitation. There are advocates of both methods. Generators with integral exciters are used on the *DC-8* and *707* airplanes whereas static exciters are used on the *Electra*, *880*, and *600*.

Frequency control of those systems using constant-speed transmissions is automatic and quite close. The basic governor holds the frequency within 1% of its set point. With a frequency discriminator superimposed on the basic governor, frequency is held to 400 ± 1 cycle. Using a 400-cycle tuning fork as a reference and a relatively simple comparator circuit, the frequency on the *DC-8* system is held to 400 ± 0.1 cycles. Automatic paralleling relays are used for paralleling the generators. Those used on the *DC-8* permit paralleling with a speed difference of up to 5 or 6 cycles and a phase angle of about 30 degrees or less. Fairly equal real and reactive load division is accomplished automatically during parallel operation.

Typical system protection includes over- and under-voltage, over- and under-speed (or frequency), unbalanced voltage (measuring either or both negative and zero sequence voltages), unbalanced current (during parallel operation) and current differential for the generators and their feeders plus a part of the bus system. System switching for most systems is semiautomatic.

PROBLEMS OF INCREASING AIRCRAFT SPEED

THE NEW COMMERCIAL JET TRANSPORTS operate at nearly twice the speed of the first *DC-6* which went into service just 12 years ago. This increase in speed has presented the aircraft electrical engineer with many difficult problems. Information presented to flight personnel relative to air speed, altitude, position, and attitude has to be more precise and reliable than heretofore. Very accurate information regarding engine rpm, temperatures, rate of fuel consumption, fuel quantity, etc., is a requirement. All of this meant that either existing instruments had to be greatly improved, or, as was frequently the case, new ones had to be developed.

In the past few years military airplanes that are capable of speeds well above Mach 1 (speed of sound) have become operational. Operation at such speeds again presented the electrical engineers with new and even more difficult problems. Control surface actuation requires much more power and the lapse of time between detection of the need for and application of corrective action must be very short. At Mach 3, in still air, the airplane is moving at about 3,300 feet per second. Therefore, many of the jobs pertaining to control of the airplane that are done by a human pilot at lower speeds, must now be done by the automatic pilot which receives its corrective signal from an electronic computer.

Automatic electronic control of high-speed aircraft has been successfully accomplished. It would, however, be incorrect to say that such control has been perfected: there is considerable work yet to be done by the electronic engineers. Incidentally, it is becoming difficult to determine when an engineer ceases to be "electrical" and becomes "electronic." In the future we, in the aircraft industry at least, may all be known as electronic engineers.

For sustained high-speed flight, that is, at speeds in the order of Mach 2 or Mach 3, temperature becomes a real problem. At Mach 3, the aircraft skin temperature is in the order of 630 F with unrefrigerated compartment temperatures in the order of 600 F. Electric and electronic equipment must either be designed to operate in this environment or be cooled by refrigeration. Refrigeration, even in subsonic aircraft, is expensive from all viewpoints—dollar, space, weight, and reduction of aircraft performance. In supersonic aircraft its relative expense is increased considerably. The ideal situation in inhabited supersonic aircraft would be to provide only the cooling required by the people and have equipment capable of operating at ambient temperature, whatever it may be. A short time ago, this seemed like a very large order, and there were a few who believed that "it couldn't be done." Well, we cannot report now that the ideal objective has been achieved, but we can report that we have gone a long way toward its achievement for a 600 F ambient. Already, many components have been developed and successfully tested in such an ambient. A paper recently presented[1] describes the progress made in the development of a constant-speed transmission for Mach 3 applications at altitudes of up to 80,000 feet. The ability of the drive to perform satisfactorily at high temperature has been demonstrated, but further development is necessary to obtain extended life under extreme conditions. The main problem appears to be the selection of materials, including fluids, with the right properties. The two classes of fluids of the greatest interest at the present time are high-temperature synthetic gas-turbine lubricants and the chlorinated silicones.

Several all-electric variable-speed constant-frequency units are presently under development. The basic principle is not new; it was described by Steinmetz many

years ago. Several attempts have been made in the past to develop such a unit for aircraft use but with no appreciable success. Solid-state switching techniques employing controlled rectifiers or their equivalent may now make it possible to develop such a unit successfully.

CONCLUSION

TO DESCRIBE IN DETAIL the present state of the art of all electrics and electronics is beyond the scope of this article. Suffice it to say, some of the highlights of developed equipment may be listed as follows: 2-pound per kva generators, 60-watt hours per pound batteries, automatic paralleling of a-c generators, high capacity systems at precise frequency, brushless generators, static exciters, precision snap switches, environment free miniature connectors, solid-state devices, transistors, diodes, thermoelectrics, high temperature wire, and many others.

What will happen in the next 25 years? We wish that we could look ahead even 10 years with any degree of accuracy. We may risk making a few predictions, however.

The electric power demand in commercial transports will continue to increase in magnitude but not as much in the next 10 years as it did in the past 10; however, the complexity of electronic gear will increase. Traffic control measures and improved navigational equipment will see to that.

Commercial transports will continue to operate at subsonic speeds for the next 10 to 15 years, and the next speed level will be around Mach 2 or 3. At that time, the demand for electric power will go up sharply. Basic system voltage will go up also.

The electric loads in military airborne vehicles will soon be much higher in some types of vehicles and the basic system voltage will go up. The next level probably will be around 440- to 480-volts a-c, phase-to-phase. Electronic gear will become far more complex, depending upon the speed and mission of the vehicle.

The cooling problem for electric and electronic equipment in Mach 4, 80,000 feet altitude aircraft will be satisfactorily solved soon; perhaps by refrigeration for some items and by direct rejection to ambient air for the majority.

Thermoelectric power generation, and perhaps refrigeration, of significant magnitude will be accomplished in aircraft relatively soon. In a recent paper[2] Dr. Zener of Westinghouse Research Laboratories stated:

> "[The present time] marks the end of a long era in which thermoelectricity was regarded merely as an interesting physical phenomenon. It marks the beginning of an era in which the full potentialities of thermoelectricity will be utilized for power conversion and for refrigeration."

In the closing paragraph of the paper Dr. Zener further states:

> "I also wish again to emphasize that the major role the new technology of thermoelectricity is going to play in our economy is in totally new uses for power generation and refrigeration, rather than in the mere replacement of currently used equipment."

Our final prediction, and the only 25-year one we will make, is that at our 100th Anniversary the historian who summarizes progress made in air- and space-vehicle electronics will comment on the primitive methods employed at the time of our 75th Anniversary.

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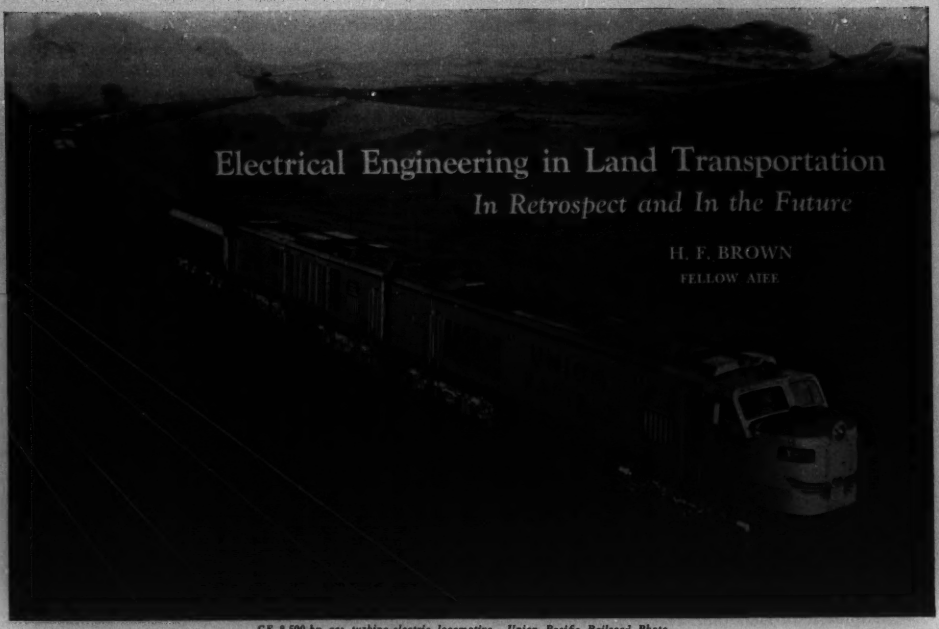

Electrical Engineering in Land Transportation

In Retrospect and In the Future

H. F. BROWN
FELLOW AIEE

GE 8,500-hp gas turbine-electric locomotive. Union Pacific Railroad Photo

A SUPERFICIAL SURVEY of electrical engineering accomplishments in the field of land transportation during the past 25 years would seem to indicate that they have not kept pace with the progress made in the power generation, transmission, illumination, communications, and other fields of application of electrical engineering. In all of these other fields of endeavor, the contributions of electrical engineering toward progress have been noteworthy and visible. During the past two decades, however, the achievements of the many noted electrical engineers who were identified with the field of electrical engineering and transportation during the years 1910 to 1935, seem to have been discarded and forgotten with the advent of the diesel-electric locomotive and the gasoline engine.

Prior to 1920, the major agencies used in land transportation were the steam railways for freight haulage and long-distance or intercity travel, supplemented by the electric interurban railways in the latter field. The electric street railways provided mass transportation in nearly all cities of any size, with the electric elevated or subway rapid-transit lines operating in most of the large metropolitan areas. Where steam motive power had met with serious operating limitations in tunnels, congested passenger terminals, or on long mountain grades, these sections of the steam railways were electrified, with economic results that gave promise of even more extensive applications subsequently.

Only one or two such extensions were made, however, and since 1938 no noteworthy extensions have been made. Moreover, during the past ten years, the electric operation of many of the formerly electrified tunnels and grades has been abandoned in favor of other operation; in one case a return to steam. The electric interurban lines had nearly all vanished by the late 20's and by 1950 the electric street cars had disappeared from all but a few of our largest cities. Only the elevated and subway rapid-transit lines remain under electric operation together with those few of the former steam railways which had electrified their suburban commuter traffic and terminals in some of these large metropolitan areas. Four steam railways that had installed long line-haul electric operation are still operating electrically.

SOME PERTINENT QUESTIONS

SOME OF THESE CHANGES have, without doubt, produced operating economies. However, are the railways in better condition physically and financially for this change? Are they giving better service to their patrons? Is the traveling public in our cities receiving better or cheaper transportation today than formerly with the other agencies? Is the traffic in our larger cities more orderly and faster because of the change?

The answers to all these questions are too well known to require much amplification in this resume. It is obvious that the almost universal use of the privately

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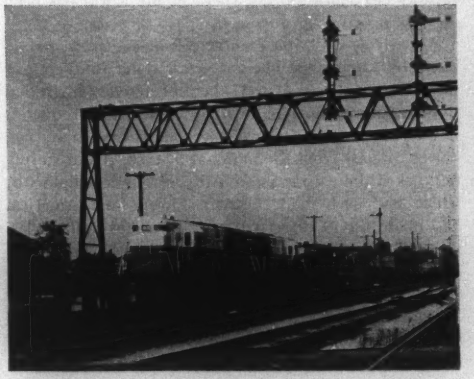
owned automobile, and the desire of each individual possessor to operate it for all of his transportation needs, has wrought great changes not only in all our former transportation agencies, but in our general economy as well. Possessing the vehicle, the owner next must have good roads and highways on which to operate. Having a voice in the government, he has voted for such roads in ever-increasing amounts until the public investment in highways now far exceeds the investment in all railways, past and present. These highways, at first free from tolls, induced many more uses than those for which they were originally intended. The trucks and buses soon appropriated a great share of the highway use, largely at the taxpayers' expense, and not only captured much of the short-haul freight and passenger traffic formerly handled by the railways on their branch lines, but competed for much of the intercity traffic and some of the long-haul traffic carried on the main lines.

INTERNAL COMBUSTION PRIME MOVERS

As far back as 1907, the large manufacturers of electric locomotives and cars had been experimenting with the application of internal combustion type prime movers to railway motive power. By 1925, they had produced the first oil-electric locomotive. In 1935, the automotive industry entered this field and since that time comparatively few steam locomotives have been manufactured. By 1942, the two largest electrical manufacturers, together with the former manufacturers of steam locomotives and the largest manufacturer of automotive equipment, were all competitively engaged in supplanting the steam locomotive with diesel-electric motive power on the steam operated railways. This business reached a peak in 1951, during which year nearly 3,500 diesel-electric locomotives were acquired by the railways.

Today, there are approximately 28,000 diesel-electric locomotives in operation on the Class I American railways handling nearly 95% of the traffic. The total generating capacity of these locomotives is well over 30 million kw d-c with the corresponding capacity in d-c traction motors. The electrical engineer has contributed his share to the development and design of the electrical equipment on this new type of motive power. He has also had to solve many complex problems in connection with the maintenance of this equipment.

Insulation and commutation under operating conditions involving oil, dirt, and heat have required new designs and materials. Silicones and other inorganic materials have replaced or supplemented former materials used for insulation. Control and ventilating problems have been successfully solved.



Two 1,800-hp General Electric demonstrator diesel-electric locomotive units in service on the Erie Railroad.

The solutions of some of these problems have enabled further development of traction motors and controls for use in the rapid-transit field. Those who use these facilities in our larger metropolitan centers are aware of the smoother and faster acceleration and higher speeds attained with the equipment which has been acquired within the past 2 or 3 years, when compared with the older equipment.

Within the past 10 or 12 years, several of the larger electrical manufacturers have been developing and experimenting with designs for oil-burning as well as coal-burning gas-turbine locomotives. One large western railway had 25 gas-turbine electric locomotives of large capacity rating in successful operation at the end of 1957, with more of still larger capacity scheduled for later delivery. A coal-burning steam turbine-electric locomotive was introduced in 1955 and was in successful operation until recently when it was retired because of its special requirements for servicing and maintenance. A coal-burning gas-turbine has been developed, but it has yet to be put on wheels.

Most of the electric locomotives in successful operation during the past 25 years had been designed generally along steam-locomotive lines with respect to driving wheel diameters, axle arrangement, and trucks. During

Four-unit 6,000-hp diesel-electric locomotive built by General Electric and operated in high-speed freight service for the purpose of evaluating components and designs.

1947, one electrical manufacturer produced a new design motor-generator type locomotive which had trucks, motors, and driving wheel diameters similar to the diesel-locomotive design for use on one of the line-haul railways electrified with single-phase a-c. To date, it has shown considerable economy as to repair costs, compared with any type of diesel or electric locomotive previously produced.

FOREIGN RAILWAY ELECTRIFICATION

ALTHOUGH THE DIESEL-ELECTRIC LOCOMOTIVE has replaced the steam locomotive as well as some of the electric locomotives on the railways of the United States, railway electrification elsewhere in the world has been actively progressing during the past 12 years.

As early as 1947, the French railway engineers, stimulated by some experimental work done in Germany just prior to World War II, became actively interested in the application of high-voltage commercial-frequency single-phase a-c to the railway contact system, taking power directly from the national 50-cycle power supply network without conversion. All previous developments, which had been made both in Europe and America, had made use of direct current at various voltages up to 3,000, or of alternating current, either 3-phase or single-phase, at lower frequencies of 15, 16⅔, or 25 cycles.

Manufacturers were asked to produce single-phase a-c traction motors for operation on 50 cycles. Some of the European manufacturers met the challenge with new designs of the single-phase a-c series-compensated commutator motor. American manufacturers were not too much interested in producing such a motor, mainly because there was no domestic market for 50-cycle apparatus and a 60-cycle motor of this type presented even greater design problems.

LOCOMOTIVE RECTIFIERS

ONE AMERICAN MANUFACTURER, however, offered another solution to the problem. The d-c series traction motor was becoming a standard on the American railways through the growing use of the diesel-electric locomotive. This type of motor had never been surpassed in design or performance by any other type of traction motor. Why change it? Why not rectify on the locomotive, the single-phase a-c delivered to the locomotive at high voltage and at any frequency, instead of at points along the way?

Two General Electric rectifier-type freight locomotive units operating in multiple under an 11-kv 25-cycle trolley wire. Each unit rates 3,300-hp continuously and weighs 197 tons.

This was not an entirely new concept. It had been tried for 25 cycles experimentally, but not too successfully as early as 1914. Rectifier design had progressed during the years, however, and the new "ignitron" type appeared to offer a possible solution. A 600-volt d-c motor car was equipped with ignitron-type rectifiers for experimental operation in 1948 and operated successfully for several years. In 1951, two experimental a-c freight locomotives were designed and were placed in successful operation in 1952. Also in 1951, some car equipment of this type was sent to France for experimental use on the 50-cycle, 25-kv test line of the SNCF (French National Railways).

All of this equipment was so successful that in 1953 one railroad in this country, electrified with 25-cycle a-c, ordered 100 motor cars of this type, for suburban service, and 10 passenger locomotives. In 1955, another a-c operated railway ordered 12 locomotives of this type for its freight operation.

In France, in 1952, 15 locomotives of this type out of a total of 105, were ordered for the new 25-kv commercial frequency railway electrification then being installed; they were placed in operation in 1955. Since this line went into operation, it has been extended, and nearly all the 50-cycle single-phase locomotives subsequently made in France for use not only in that country, but for export to Portugal, India, and China, have been, or will be of this type. Locomotives of this type have also been made in Belgium for use in the Congo.

This was the contribution of American electrical engineering to the new concept of railway electrification, using power directly from the 50- or 60-cycle industrial

Two-unit motor-generator locomotive operating from 11-kv 25-cycle trolley.

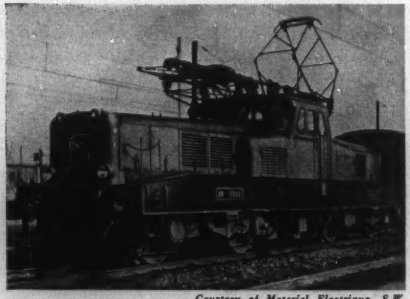
or commercial electric power network. The name of L. J. Hibbard will always be remembered in connection with the application of the ignitron rectifier to railway motive power in the United States.

Further progress is being made with solid rectifiers instead of the mercury-arc type. Already equipment using solid rectifiers is being operated experimentally in England.

RAILWAY ELECTRONICS

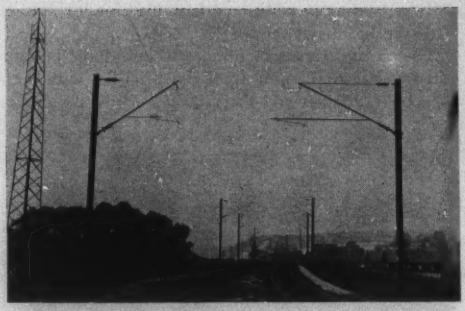
DURING THE PAST TWO DECADES, the electrical engineer has been applying the progress made in electronics and communication equipment to the railways for increased safety and economy. Signal systems have been improved. Cab signaling, which allows the engineman to have continuously before his eyes the signal aspect for the track section ahead, regardless of outside visibility, has been developed to a high degree of perfection. Centralized Traffic Control (CTC), which allows remote control of train operation over long distances or entire divisions under the visual supervision of a single dispatching office, are in common use. Electric devices for the sorting and speed control to reduce delays and damage to lading of freight cars in large hump yards, have been installed in a number of these new freight terminals. Microwave and carrier systems are assuming larger and more complex duties in railway communication systems. The engineman in his cab, is able to communicate by train radio with the crew at the rear of his train, or with the wayside dispatching stations. Faster train braking with electric controls, and the detection of hotboxes by means of electric wayside devices have been devised and are in use. In passenger cars, the comfort of the traveler has been increased by air conditioning and by the use of fluorescent lighting.

It can be said with certainty that the electrical engineer has not been idle in the land-transportation field during the past two decades, and the AIEE *Transactions* have recorded in detail his activities.



Courtesy of Materiel Electrique, S.W.

View of 3,600-hp 84-ton 25-kv 50-cycle single-phase electric locomotive for French National Railways (SNCF). More than 350 locomotives of this type are in service or under construction in France for SNCF and for export.



Lightweight catenary contact system for 25-kv 50-cycle single-phase electrification in France for SNCF.

WHAT OF THE FUTURE?

WHAT WILL THE NEXT 25 YEARS develop in the land transportation field?

Man's activities in the future cannot be predicted with the exactitude that events such as tides, eclipses, and other astrophysical events can be. Nevertheless, trends of today do indicate with a fair degree of accuracy, what may be expected in the near future.

In the field of railway transportation, present rules indicate:

1. The cost of repairs of diesel locomotives, as their service life increases, is becoming disappointingly high. High maintenance cost however, is a characteristic of all internal combustion type prime movers, indicative of a short economic life. The indicated service life is possibly but one half that of the electric locomotive.
2. The trends in liquid fuel costs are pointing to much higher costs in the near future. The United States currently produces 35% of the free world's supply of this type of fuel, but is consuming 55%, annually.
3. Electric power is becoming more and more available in all parts of the country, as a result of the increasing expansion of power networks interconnecting large generating stations of high efficiency.

Certain railways having high traffic density will assay these factors for their own economic benefit, and electrification will again find an application on some of the railways in this country, as it has in Europe and elsewhere in the world.

This future railway electrification will not be handicapped by the necessity for railway owned transmission lines, power plants, conversion stations, or costly overhead structures. A lighter overhead contact system, working at 25 kv will be supplied with single-phase 60-cycle power at points where the railways intersect the commercial power transmission lines, in the same manner that other industry is now supplied. Power utilities are becoming aware of the potentialities of the

railway load as an additional base load for integration with the industrial loads.

The electrical manufacturers will once more become interested in developing these potentialities with both the power utilities and the railways. Thus, the manufacturers will progress still further the engineering achievements of those who blazed the trail 50 years ago. All this is simply a matter of time.

View of Chicago transit system roadbed sandwiched between sections of the Congress Street Expressway. This is one city's partial solution to the problem of integrating modern mass transportation facilities with space requirements of vehicular traffic.

In the field of urban transportation. Most of our large cities are becoming strangled by unrestricted automotive traffic of all kinds. Freight cars are no longer confined to the railways; equipped with rubber tires, they now choke traffic at will on narrow city streets, whether in motion or parked at the curb. Every business street has become the equivalent of a railway siding, so used at the pleasure of the shipper or trucker, and at the expense of the taxpayer.

Every new throughway built into the city tends to increase the city's traffic congestion. To provide adequate terminal facilities for this enormous automotive traffic can only be done by scattering the business areas and losing the value of the city as a business center.

Eventually, the individually owned automobiles and heavy trucking vehicles may be legislated out of some of these important congested centers, and replaced with modern mass transportation facilities. Electric operation will again play an important role in such facilities. Already, Chicago has indicated one solution by the combination of its rapid transit system with the new Congress Street expressway. Chicago has also had for many years a little known, but effective freight subway system, which might be emulated by other cities.

Electrical engineers and the AIEE Land Transportation Committee will continue to find much work to do during the next 25 years, both in railway electrification and in the urban and suburban transit fields, to assist in bringing about improved operating economies for the transportation agencies, and better service to the public.

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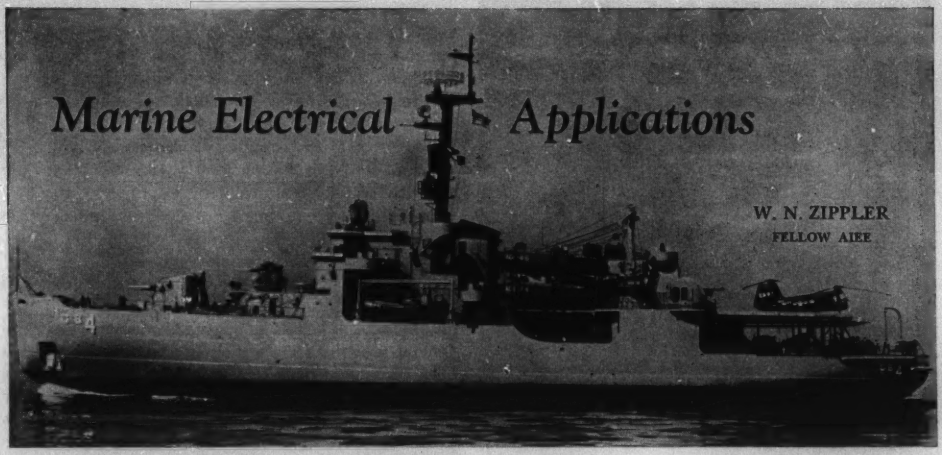
Marine Electrical Applications

W. N. ZIPPLER
FELLOW AIEE



The Navy's newest and most powerful icebreaker, USS Glacier. Official photograph, U. S. Navy.

THE TREMENDOUS DEVELOPMENT of shipboard electrical applications in the 25 years from 1934 to 1959 can best be shown by a brief review of that state of the art in 1934, contrasted with present-day installations.

In 1934, practically all electric power at sea was 240/120 volts d-c. The U. S. Navy had just decided to construct destroyers with a-c- plants and was settling upon 450 volts, 3-phase, 60 cycles as the optimum generator voltage and frequency for their purposes. All commercial vessels, cargo ships, and passenger liners were provided with d-c plants, and would be so built until the T-2 tankers were built in 1938. Dry cargo vessels were built with d-c plants until the Mariners came along in 1952.

In 1934, it was a rare passenger vessel with as much as 2,000 kw installed generator capacity. Today, designs with 10,000 kw installed capacity are under consideration. The liberty ships, although built from 1942 to 1946, had 60 kw installed generator capacity. Almost all modern cargo ships have 1,200 kw installed. The installed generator capacity of Navy destroyers today is about 15 times as great as that on the first destroyers with a-c plants.

Naturally, the increased usage of electric power has made necessary the development of lightweight equipment. An obvious step in saving weight has been the change to 450/120-volt a-c systems. A comparison of specific plant weight shows the following:

	Kilowatts of Generator Capacity Per Long Ton of Electric Plant Weight	
	1934	1959
Passenger Vessels	8	14
Cargo Vessels	7	10
U. S. Navy Destroyers	6	15

In addition, the weight of a-c plant components has been steadily reduced. As a specific example of the weight reduction achieved, the main switchboards on the *SS America*, one of the last passenger liners to be built with a d-c plant, weigh 12.5 pounds per kilowatt of generator capacity, whereas the main switchboards on a recent passenger vessel within an a-c plant weigh only 4.5 pounds per kilowatt of generator capacity.

Noteworthy developments over the past quarter century have been made in electric propulsion machinery, switchgear, lighting, cargo winch drives, navigational equipment, and in naval equipment.

Electric propulsion machinery in 1934 can be typified by the *MS Triumph*, which had d-c diesel electric propulsion machinery consisting of four generators and one motor. The d-c motor was of the double-armature type and rated at 4,000 shaft horsepower, 60 rpm, 1,500 volts. To limit the voltage to ground a series circuit was formed of two generators, one motor armature, two generators, and the second motor armature.

The most recent electric propulsion plant is that of the U. S. Navy Icebreaker AG B4, the *USS Glacier*. The two shafts of this ship are each driven by a single 10,500-hp d-c motor. Each motor is supplied by five diesel-driven generators in parallel.

Switchgear designs have changed from the live-front boards which were conventional for the 230-volt d-c plants of 1934 to the compact metal enclosed dead-front switchboards used today.

Shipboard lighting in 1934 was, of course, confined to incandescent lamps. Lighting loads have increased at least as much as other electric loads. However, the change to a-c plants and the development of fluorescent lighting have permitted application of higher lighting

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Courtesy Westinghouse Electric Corp.

Propulsion motor for *USS Glacier*. Armature and frame of 10,500-hp propulsion motor in manufacturer's shop.

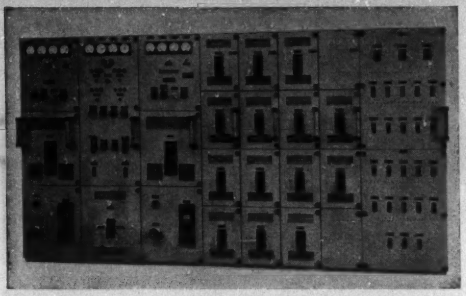
levels where desired without excessive increases in wattage, important on today's air-conditioned ships. Careful design is vital to insure that the higher lighting levels do not cause uncomfortable glare and that the hospitably warm appearance of the older vessels is not lost in today's advanced installations. It is of interest to note that the lighting installation on passenger vessels has gone from 340 watts per person in 1934 to 540 watts per person in 1959.

Cargo winch drives on d-c ships in 1934 usually employed constant voltage supply, and required large resistor banks and multitude of contactors to obtain the speed–torque characteristics necessary for efficient cargo handling. Today, with a-c plants universal, it is necessary to provide motor–generator sets to supply cargo winch driving motors. However, in the latest cargo winch drives, with variable voltage supply and using for control and excitation purely static devices such as dry-plate rectifiers and magnetic amplifiers, it has been possible to obtain improved speed–torque characteristics in less space with almost complete elimination of contactors and with no heavy power resistors.

Twenty-five years ago the only electrically operated navigational aids in common usage were radio telegraph, radio direction finders, and sometimes logs. The general growth of electronics is well known, and has been accompanied by similar growth in shipboard application. Today, even tramp steamers are rarely to be found without a radar antenna showing above the house tops. Loran and Decca navigation systems are commonly in use to aid in determining ship's position with greater accuracy than used to be possible. Radio telephone is almost universally used for short-range communications. Facsimile equipment is common to receive up-to-date weather information. Crews are insisting on facilities for use of personal radios in their staterooms.

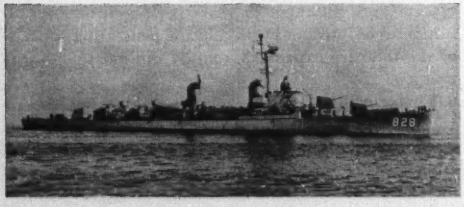
Advances in naval equipment have been too numerous for exhaustive recapitulation. In addition to developments such as those described for the *USS Glacier*, the Navy has fostered outstanding contributions to the art. For example, today all electric equipment on

View of engine room and main switchboard of *SS America*. This ship, built in 1937, has 240/120-volt 3-wire d-c electric plant. Main switchboard is live front, controlling and distributing the power from four 600-kw generators in a grounded-neutral system.



Main switchboard of modern cargo ship. It is a modern design of dead-front board, controlling and distributing power from two 500-kw 450-volt 3-phase 60-cycle a-c generators in a 3-wire ungrounded system.

Radar mast of large passenger vessel. The installation of radar on modern ships required some means of raising the antenna above the rest of the ship's structure on a mast such as that shown. Mast also provides convenient locations for enclosed crow's-nest, radio antennas, flag halyards, and wind direction and intensity instrumentation. Broom on the right indicates completion of a successful trial trip wherein the ship met or exceeded all specification requirements.



View of USS *Timmerman*. While basically a Class DD710 destroyer, advances were made in the hull layout and design as well as in the propulsion machinery and electric plant.

naval vessels, from fluorescent lighting fixtures to electronic equipment, including circuit breakers and switchgear generally, is required to be of demonstrated shock- and vibrationproof design.

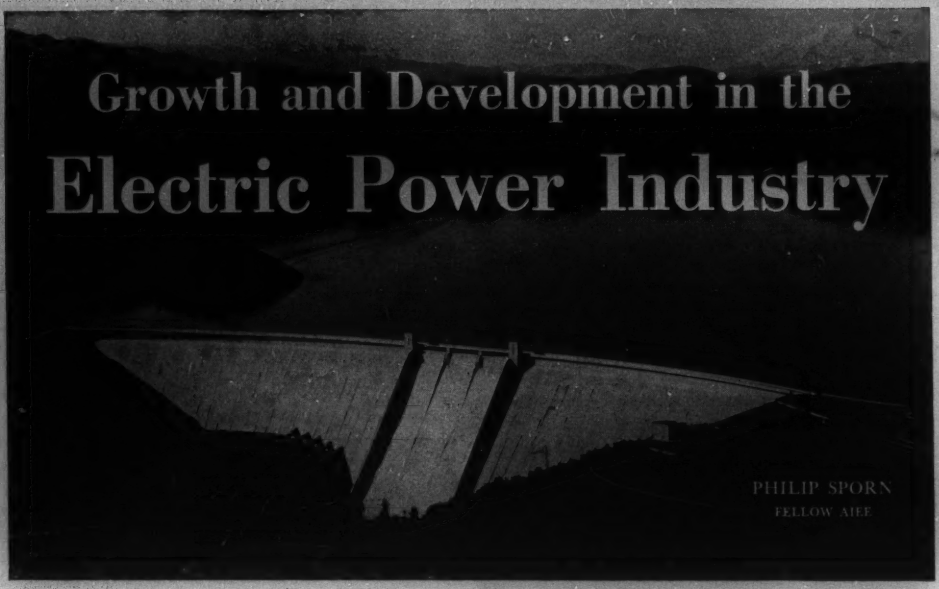
Perhaps the most interesting single development by the Navy is the electric plant on the *USS Timmerman*, the experimental destroyer delivered in 1952. This plant has been described in several papers, but is briefly described here for ready reference.

The *USS Timmerman* was built with a 400-cycle 1,000-volt 3-phase a-c electric plant. Two 600-kw steam turbine–generators were installed. One 250-kw diesel generator and one 200-kw gas turbine–generator were also installed for emergency power supply. It was necessary to install a large motor–generator set to convert shore power at 450 volts and 60 cycles to 1,000 volts at 400 cycles. Squirrel-cage motors were installed, many with synchronous speeds of 24,000 and 12,000 rpm; more at 8,000 and 6,000 rpm. Practically every power-consuming device on the ship was supplied power at 400 cycles: fluorescent lights, ventilating fans, cooking equipment, pumps, compressors, etc. As a result, a reduction in weight of over 55% resulted for the items developed for the experimental electric plant.

It was necessary to study all components of the plant in detail. New circuit breakers were required. Novel motor insulation schemes were developed. Power and control transformer noise required concentrated effort to control audible noise. Many useful designs were developed which, in various modifications, can be found applied widely in improved designs on naval and commercial ships today.

The past quarter century has seen a considerable increase in the rules and regulations applicable to marine electric plants. The AIEE Standard No. 45, Recommended Practice for Electric Installation on Shipboard, has grown from 91 pages in the 1930 edition to 161 pages in the 1958 edition. The U. S. Coast Guard, by Congressional authority, has replaced the Bureau of Marine Inspection and Navigation as the responsible agency for enforcing standards of safety at sea. The Coast Guard regulations covering electrical engineering are printed in a volume of over 130 pages and, even so, do not include certain regulations peculiar to individual classes of vessels which are printed in other volumes of the Coast Guard regulations. There has recently been published by the International Electrotechnical Commission, an affiliate of the International Organization for Standardization, the first edition of "Recommendations for Electrical Installations in Ships," in 175 pages. The American Bureau of Shipping Rules for Building and Classing Steel Vessels incorporates a section on electrical equipment which has grown about 50% from 1936 to 1958. Of course, other requirements must be met, such as those of the Public Health Service and the Federal Communications Commission. No attempt will be made to estimate either the number of individual specifications or the pages thereof which are applied by the U. S. Navy Department to naval shipboard electric plants.

Growth and Development in the Electric Power Industry



PHILIP SPORN
FELLOW AIEE

Shasta Dam, 375,000 kw, Sacramento River, Calif., gross head 400 feet, 4 units. Photo courtesy U. S. Bureau of Reclamation

THE HISTORY of the electric utility industry in the United States in the 25 years since AIEE celebrated its Golden Anniversary in 1934 has been that of remarkable physical growth. The technical achievements of the industry during this period helped to foster this growth and were, in turn, stimulated and made possible by it. During this 25-year period, electric utility generation expanded by well over 700%, or at a rate almost 2½ times as fast as the increase in the real gross national product (GNP) after eliminating changes in the price level. The expanding use of electric energy in every aspect of American life has contributed to and, in turn, has been made possible by the rising standards of living and the increased productivity this country has enjoyed in this period.

In 1934, the electric utility industry had only 24.7 million customers, but by the end of 1958, the total had increased almost 2½ times to over 56 million. While this was partly the result of an expanding population, it was in large measure attributable to the expansion in electric service to a larger portion of the population so that well over 95% of the total residences in the United States, or all but the most remotely located, now have central station electric service available, compared with only 65% in 1934. Contributing to this result was the substantial completion of the program of rural electrification—undertaken initially by the private utilities and, later, more intensively by both the private utilities and the Rural Electrification Administration. At the end of 1934, almost 744,000 farms, or slightly less than 11% of the total number of farms in the United States, were served by the utility industry. By 1958, however, the extent of rural service was almost equal to that found in urban areas, with almost 95% of the total farms receiving utility service.

The 20.4 million residential customers in 1934 used an average of only 629 kwhr per customer; in 1958, the more than 46 million residential customers consumed 3,385 kwhr per customer. In the same period, average price per kwhr had fallen from 5.33 to 2.52¢, despite a more than doubling in the consumer price level.

Similar growth took place in the commercial and industrial consumption of electric energy. Electricity used per production worker man-hour rose from 4.07 kwhr in 1934 to more than 9 kwhr in 1958, excluding energy used by the aluminum industry and the Atomic Energy Commission. In the total, electric utility generation grew in these 25 years from a little over 87 billion to 641 billion kwhr, and the generating capacity of the industry expanded from 34 million to 140 million kw.

This growth in the past quarter century has also involved a change in the character of a considerable part of the industry from relatively small, more or less isolated systems into large integrated systems, many of these in turn being interconnected in larger pools of systems, with the advantages of mass production and

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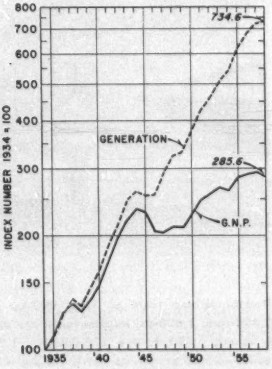
transmission of electric power at costs lower than could have been achieved by the smaller systems. This phase of the industry's development has been made possible in large part by a number of important technological achievements, and the large systems themselves have made possible the incorporation of cost-saving technological developments which would otherwise not have been made. For example, the savings in construction cost per kilowatt of capacity by building larger units would not have been possible without the large systems able to absorb them, and the savings in fuel costs now being achieved through the use of larger, more efficient units and the transmission of large blocks of power from plants built close to a source of fuel and condensing water would not have been possible without the need for large quantities of power in single systems.

Important forward strides in technology have taken place, as will be seen in the following discussion, in every phase of the industry's operations.

STEAM–ELECTRIC GENERATION

THE EXPANSION of electric utility capacity from 34 million to 140 million kw was more than a simple multiplication in kind. As a consequence, the generating plant, particularly the steam–electric plant, being installed on the utility systems of the United States today can hardly be classified as of the same species as those installed in 1934. The size of units, the steam temperatures, the pressures, and the efficiencies were all almost undreamed of, or even considered impossible in 1934. The growth of unit sizes in this period has been most notable. In 1934, the typical "large" turbine–generator unit delivered for power system installation was 40,000 to 50,000 kw. In 1937, a 40,000-kw unit was the largest single-shaft 3,600-rpm machine installed up to that time. Today, a tandem-compound single-shaft 3,600-rpm unit of 250,000 kw is operating, and one of 325,000 kw is on order. At the same time, cross-compound units have progressed from the 3,600/1,800-rpm combinations of 90,000 kw that were typical in 1939, to the 325,000-kw units now in operation and the 3,600/3,600-rpm 450,000-kw units now under construction and 500,000-kw units now on order.

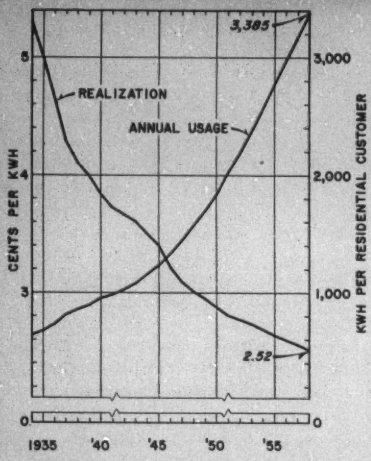


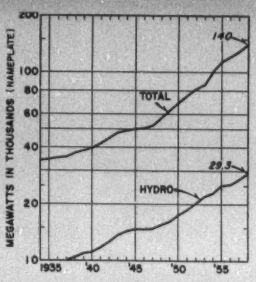
Comparative growth of electric utility generation and real gross national product, excluding price-level changes.

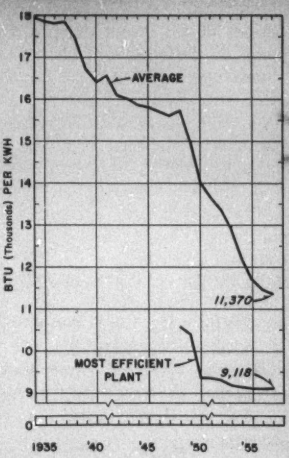
While these advances have been the result of many technical improvements, perhaps the most significant as far as the generators are concerned are the advances made in methods of cooling. In this development, the most important single step has been the use of hydrogen as the coolant, first at 0.5 psi (pounds per square inch), and later increased to 15, 30, and, finally, to 45 psi. The more recent development of inner cooling of conductors, both stator and rotor windings, has made possible the latest increases in unit sizes to what were considered impossible figures only a few years ago. On the turbine, the development of longer last-stage buckets—and even greater length is now under development—along with multiflow exhausts, has made possible the handling of the large volumes of steam required in units ranging in size from 325,000 to 500,000 kw.

Along with and contributing to the increased unit size have been the major advances in turbine and boiler technology in steam temperatures, pressures, reheat, and size and design of boilers. Steam temperatures of 900 F were first achieved in 1936, and in two steps this was advanced first to 925 F in 1937 and to 940 F in 1940. Further development was of necessity suspended during World War II, but in 1947 a major step was taken in the Atlantic City No. 7 unit, which advanced temperatures to 1,000 F. This was quickly followed by 1,050 F at Sewaren in 1948, 1,100 F at Kearny in 1953, 1,150 F for Philo No. 6 in 1957, and finally, the maximum to the present time, 1,200 F for Eddystone No. 1, now under construction. Although the economic validity of the very high temperatures of the last two steps remains to be established, it does represent a remarkable technical advance in steam temperatures of 300 F in the past 25 years which has left its mark on heat energy conversion technology.

Pressure technology, having broken through the supercritical barrier, may be said to have undergone even more notable advances than those in temperature. Pressures of 1,100 psi were achieved in the early 1930's, but developments were not extended appreciably beyond this until the 2,400-psi Twin Branch No. 3 unit was installed in 1940, largely as an advanced experimental prototype. Although World War II delayed further development, this 2,400-psi installation paved the way for the highly successful postwar boiler technology in the 2,000-psi range, which prevailed until the 4,500-psi supercritical unit was installed at Philo in 1957. This unit, having a capability of 107,000 kw and, parenthetically, occupying the space formerly occupied by a 40,000-kw unit of 1925 vintage, was developed as an experimental prototype which has led the way to construction of a number of larger-size units of a similar type. This has been extended to 5,000 psi, 1,200 F in the 380,000-kw Eddystone No. 1 unit referred to earlier. More particularly, it has provided the basis for the design of two 450,000-kw units on the American Electric Power (AEP) System, where, because of the relatively lower value of thermal savings







(*Left*) Increase in average annual kwhr use and decline in cost for residential consumer. (*Above*) Growth in electric utility industry total and hydro generating capacity. (*Right*) Thermal efficiency improvements. Declining heat rate, industry average, and best plant.

made possible only at the expense of higher costs for more expensive alloy materials required for higher temperatures, the temperature and pressure levels were backed off to 1,050 F and 3,500 psi. For similar reasons a second Eddystone unit is being designed for 3,500 psi and 1,050 F.

The reheat cycle which was initiated early in this period has now become general practice and has made possible substantial gains in thermal efficiency. Single reheat applications were developed as follows:

Date	*Initial Temperature*	*Reheat Temperature*
1940	940 F	900 F
1949	1,050 F	1,000 F
1953	1,050 F	1,050 F

More recently, the application of a double-reheat cycle has been developed. These include the experimental 1,150/1,050/1,000 F at Philo; the experimental 1,200/1,050/1,050 F for Eddystone No. 1, and the 1,050/1,050/1,050 F for the 450,000-kw units at Breed No. 1 and Sporn No. 5. These basic improvements in the heat cycle, along with many other refinements in boilers and turbines, have increased thermal efficiencies markedly. Compared with an average heat rate of 16,500 Btu per kwhr for units installed in 1934, the average for units installed in 1958 was close to 9,900 Btu per kwhr, and for one whole system, the AEP System, average over-all system heat rate in 1958 was reduced below 10,000 Btu per kwhr. This is all the more significant considering that it was only as recently as in 1950 that the Philip Sporn Plant was the first to achieve an average plant heat rate below 10,000 Btu per kwhr.

Along with improvements in thermal efficiency, the great increase in unit sizes has been one of the major factors in holding the cost per kw of capacity down to levels approaching those of a decade ago, despite an

Courtesy Commonwealth Edison Company

Modern turbine room of 1934, State Line Unit 1. 208,000 kw, triple cross-compound, 1,800/1,800/1,800 rpm. Main steam 600 psi, 730 F, reheat 500 F; optimum heat rate is 12,950 Btu; average annual heat rate 13,355 Btu.

Courtesy Tennessee Valley Authority

Modern turbine room of 1,600,000-kw Kingston steam plant. Nine 3,600-rpm, 1,800-psi tandem-compound units; four 150,000-kw, 1,000 F, reheat 1,000 F; five 200,000-kw, 1,050 F, reheat 1,000 F. Unit boiler–turbine layout, generator cooling H_2 at 15 and 30 psi.

almost doubling of construction costs in the postwar period. This is readily illustrated, as noted in the foregoing, by the space occupied by the Philo No. 6 Unit, almost tripling the capacity previously installed in a given area. In addition to the savings in construction costs made possible by increases in unit capacity, savings in operating expense have also been made possible through a reduction in the manpower requirements from upwards of 1 man per 1,000 kw 25 years ago to as low as 0.25 man per 1,000 kw today. Even more gratifying is the indication that this trend is not at an end, and that even lower manpower requirements per unit of capacity can be expected on the newer 450,000- and 500,000-kw units. The reduction in manpower requirements has been materially advanced by the use of centralized and largely automatized control arrangements along with the general adoption in the postwar period of the single-unit boiler–turbine combination for even the largest units, including the 450,000- and 500,000-kw units now under construction. The million-pound-per-hour steam boiler has now been replaced by the large steam generators rated at from 3 to 4 billion Btu-per-hour input. The increase in efficiencies has managed to offset a substantial part of the effect of the increases in fuel cost since the end of the war.

HYDROELECTRIC GENERATION

ALONG WITH THE LARGE EXPANSION of our steam–electric generation, progress has not been static in the further development of hydro resources not only in all areas of the United States where hydro potential is available, but also to a notable extent in Canada. An indication of progress in this country is given by the growth of installed hydro capacity during the past 25 years from a figure of 9,345,000 kw in 1934 to 29,318,000 kw in 1958, along with an increase in total hydro energy generation from 32,684 million kwhr to about 140,000 million kwhr in the same period.

Among other major developments are those completed and under way on the Niagara and St. Lawrence Rivers. At Niagara, the Lewiston Plant of 1,950,000 kw will incorporate the largest hydro units to date, 150,000 kw each, compared with Grand Coulee units of 108,000 kw each. This plant and its associated plant, the Tuscarora pump–hydro 240,000-kw plant, will make a total project of 2,190,000 kw, the largest single project to be developed in this country as well as in this hemisphere. Completion of this project is scheduled for 1962. The St. Lawrence development at Barnhart Island comprises essentially two plants in one, each of the same rating, the Robert H. Saunders–St. Lawrence Generating Station in the Canadian portion and the Robert Moses Generating Station on the American side. Both of these plants are now in full operation, each with a capacity of 912,000 kw.

Elsewhere in the United States, the principal areas of development have included the major projects in the Pacific Northwest, such as Bonneville, Grand Coulee, Cabinet Gorge, Ross, Brownlee, and many others; the Shasta Dam, along with numerous smaller projects, in California; Missouri River plants, such as Garrison and Fort Randall; Clark Hill and John Kerr in the Southeast; the numerous plants on the Tennessee and its tributaries involved in the TVA (Tennessee Valley Authority) complex; and finally, the New England area.

In Canada, a number of large projects on the order of 1 million kw or larger have been completed and others are under construction. These include the Ontario Hydro Electric Commission Adam Beck No. 2 Plant and pump–hydro installation at Niagara Falls, and the Robert H. Saunders Station on the St. Lawrence at Barnhart Island mentioned earlier. Quebec Hydro-Electric Commission projects include the 1.5 million kw Bersimis development and the Beauharnois Plant on the St. Lawrence River near Quebec. Aluminum Company of Canada has carried out an impressive group of hydro projects, including Kitimat in British Columbia with its 1,250,000-kw underground powerhouse, high-altitude transmission line, and the Lake St. John complex of plants totaling some 2 million kw on the Saguenay and Peribonka Rivers.

With many of the more favorable hydro sites already developed, a trend toward more economical methods of dam construction has made a significant contribution to extending the economic feasibility of remaining sites. In particular, two types of construction may be cited, first the rock-fill construction in which the waterproofing is obtained by means of a deck on the upper face made of asphaltic cement to give it the necessary degree of flexibility without cracking. The other type consists of a combination rock and earth fill, the latter comprising a core of well-packed clay soil in between rock fill on both upstream and downstream sides.

Considerable interest also has been evidenced in pump–hydro developments although total capacities involved so far are not great. Projects during the past 25 years include the Hiwassee Plant of TVA, the Colorado Big Thompson project at Estes Park, the Tuscarora and Adam Beck projects on the Niagara River previously mentioned, and a new project under development at Smith Mountain, Va. The trend in later developments has been toward the use of a single unit to serve as both a generator–turbine combination and a motor–pump combination as compared with separate units for each function.

Although a heavy program of hydro construction has been carried out in this country, it is significant to point out that generation has grown even faster so that the proportion of United States over-all power requirements contributed by hydroelectric plants has shown a considerable decline over the past 25 years. With the one exception of the Pacific Northwest area, this is true even in areas of large hydro potential such as in California, as well as in the TVA system where more than two thirds of the total power requirements are now generated by steam. Likewise, the Hydro Electric Power Commission of Ontario is basing future growth of generating capacity principally upon steam. The extent to which the expansion of steam–electric genera-

Courtesy Indiana-Kentucky Electric Corporation

Clifty Creek plant, with 682-foot stacks for proper diffusion of boiler effluents. Six cross-compound 215,000-kw 3,600/1,800-rpm units. Main steam 2,000 psi, 1,500 F, reheat 1,050 F. Generator cooling H_2, 30 psi. Unit boiler–turbine layout.

Courtesy Washington Water Power Company

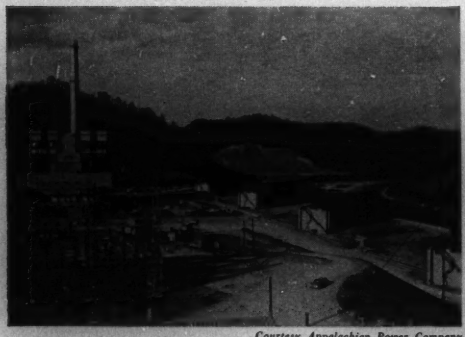
Cabinet Gorge, 200,000 kw, Clark Fork, Idaho. Gross head 97 feet, four 50,000-kw units.

Courtesy Consolidated Edison Company

Modern large cross-compound unit, Astoria No. 3. 335,000 kw, 3,600/1,800 rpm. Main steam 2,000 psi, 1,050 F, reheat 1,000 F. Generator cooling H_2, 30 psi.

Courtesy Quebec Hydro-Electric Commission

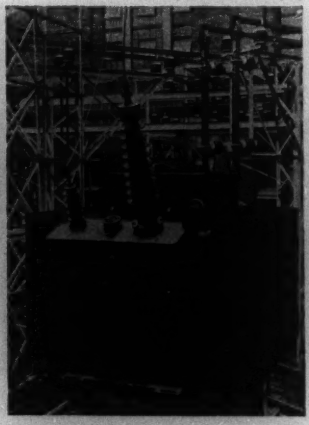
Beauharnois hydroelectric plant, on St. Lawrence River near Montreal. Head is 80 feet. In operation are fourteen 40,000-kw units and twelve 42,500-kw units. Under construction are ten 55,000-kw units.



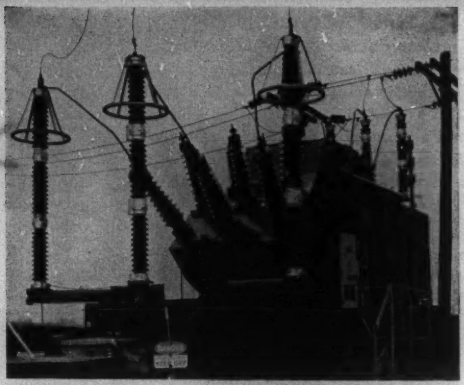
Courtesy Appalachian Power Company

Modern cooling tower plant, Clinch River Nos. 1 and 2. 225,000 kw each, cross-compound 3,600/1,800 rpm. Main steam 2,000 psi, 1,050 F, reheat 1,050 F. Generator cooling H_2, 45 psi. Four cooling towers for 100% cooling water requirements.

Courtesy Ohio Power Company

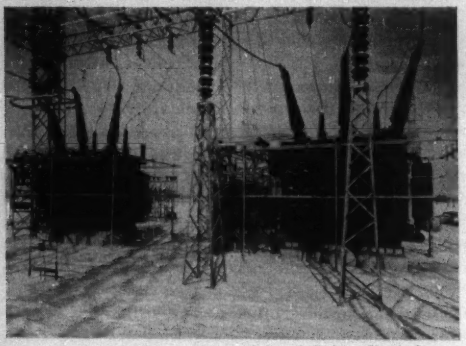


Transformer using forced-oil circulation, forced-air cooling, and grain-oriented steel. Three 15,000-kva 138,000-volt single-phase units in step-up bank at Phile, Ohio.



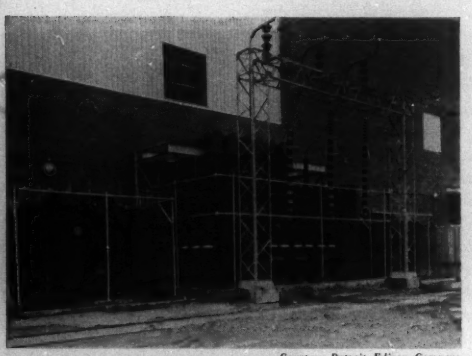
Courtesy Westinghouse Electric Corporation

Railway car mounted 50,000-kva 3-phase, 138 kv–69/34.5 kv mobile transformer at Lima, Ohio.



Courtesy Indiana & Michigan Electric Company

200,000-kva 345/138-kv 3-phase autotransformers at Olive Station, Ind. Reduced insulation design 1,050-kv basic insulation level.



Courtesy Detroit Edison Company

Large 3-phase step-up transformer, 370,000 kva, 17/129 kv, at St. Clair Station, Detroit, Mich. General Electric FOA design.

tion has outstripped the growth of hydro resources in the United States is indicated by the drop in percentage of total generated hydraulically from 37.5% in 1934 to 21.8% in 1958.

TRANSFORMERS

IN KEEPING with the growth of generator unit sizes as well as with over-all growth of systems, power transformer sizes have been increased to capacity ratings hardly visualized 25 years ago. This has come about by improvements in design from the standpoint of insulation, efficiency in the use of materials, improvements in the quality and characteristics of materials, and finally, by drastic changes in shipping methods, all of which have made possible larger and larger capacities within practical space limitations.

One of the first steps in this direction was the one-step reduction in basic insulation level (BIL) for high-voltage transformers, 115 kv and above, made possible by more effective co-ordination of insulation strength and lightning arrester protective characteristics. An example of this was the use of a 550-kv BIL, reduced from 650 kv, for 138-kv transformers, tried out successfully as early as 1934, and gradually adopted as standard practice thereafter.

Other important steps were the development in 1941 of grain-oriented steel, permitting a 1/3 increase in core flux density, and the introduction of the FOA design, combining forced-oil circulation and forced-air cooling. Further reduction in oil and material requirements was obtained by the use of special tanks designed to fit core and coils more closely than previous straight-walled tanks.

A bold step to insure the adequacy of these transformer designs to withstand exposure to lightning surges under field conditions was the introduction in the early part of this 25-year period of the practice of using impulse tests for controlling the quality of transformers in regular production as well as for research purposes on new development models. This has paid off in reducing transformer failures in this country caused by lightning to very small proportions.

With the solid background of research and technology in transformer design and construction, including the various developments leading to concentration of larger capacities in smaller dimensions, the manufacturers were able to take in their stride the design and construction of 345,000-volt transformers when these were first required in 1953. The first group of these transformers, designed with a basic insulation level of 1,175 kv, 1½ steps below the full 1,550-kv level, were 150,000-kva 3-phase autotransformers, 345 kv to 138 kv with 37,500-kva tertiary windings. Subsequent installations of larger 345-kv transformers include 3-phase 200,000-kva autotransformers similar to the original 150,000-kva units and a 3-phase 275,000-kva 345-kv generator step-up transformer.

Consistent with the general adoption of the unit arrangement for turbine, generator, and boiler installations, it is significant that available sizes of single-

Courtesy Commonwealth Edison Company

100,000-kva 3-phase 22-kv ±38-degree phase-shifting transformer, at State Line Station in Illinois. Westinghouse design.

unit transformers have kept pace with the increase in sizes of generators and turbines. These transformers have progressed from 315,000-kva 3-phase units in 1955, to the largest to date of 380,000-kva 3-phase, both for generator step-up purposes. As in the case of large capacity generators, the introduction of forced cooling which has made possible the development of improved techniques in cooling, in this case primarily in the physical arrangement of conductors and insulation, has been an important factor in making these high-capacity ratings possible.

A further step in reducing the relative size, cost, and weight of transformers, particularly in the higher voltage ratings, is an additional lowering of BIL which is now being tried out, taking advantage of improvements in accuracy of protective levels of lightning arresters. For 345-kv transformers, this has been a full 2-step reduction in BIL from 1,550 kv to 1,050 kv compared with the 1,175-kv level or 1½-step reduction based in earlier designs. At lower voltages, such as 138 kv, 230 kv, and others, a similar 2-step reduction in BIL is being tried out in some installations, including a number of 138-kv transformers with 450-kv BIL, two steps below the full insulation level of 650 kv. Although the largest 345-kv transformers now under construction using the 1,050 BIL are the 275,000-kva, 3-phase step-up units for the Breed 450,000-kw generators, manufacturers today indicate willingness to undertake building such units in ratings as high as 550,000 kva or even higher.

TRANSMISSION SYSTEMS

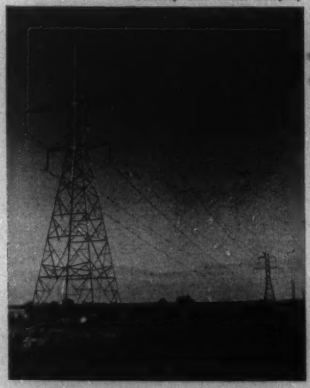
DEVELOPMENTS IN GENERATION, which have resulted in large capacity units and in an increasing number of both steam and hydro stations with more than a million kw of capacity, would not have been possible under the geographical limitations of water, land, and availability of fuel without major expansion of transmission systems capable of moving large quantities of power economically to centers of load. To a considerable extent and particularly on systems where transmission distances were not excessive, the necessary expansion of transmission capacity has been obtained at voltage levels already in use, such as 115 kv, 138 kv, and 161 kv, not to mention 230 kv, which was already in use on a number of systems 25 years ago, having been initiated in California in 1923.

While there exist a number of examples of major expansions in transmission capacity at existing voltage levels, these are exceptional. In general, the movement of increasingly large quantities of power at these lower voltages has become more and more burdensome from the standpoint not only of the multiplication in number and cost of transmission lines required, but also from the standpoint of the serious right-of-way problems involved, particularly in areas of expanding populations and suburban residential build-up. For many systems, a satisfactory solution has been the adoption of 230-kv transmission, more than 15,000 circuit-miles of which is now in operation in the United States alone. It has been a popular voltage, not only for superposition on systems up to 115 kv and even 138 kv, but also for bulk power transmission on many hydro developments involving long distances, both in this country and in Canada.

A notable exception to this pattern was occasioned by the Hoover Dam project in the early 30's, involving transmission of a large block of power some 275 miles to Los Angeles. For this purpose, 230 kv was considered inadequate and new ground was broken in developing a 287-kv transmission system including all related equipment. Although this system, including a third line added in 1939, was successful in operation, expansion elsewhere during the next decade continued at the 230-kv level.

In the meantime, other systems still using 115- or 138-kv transmission were recognizing the need for a higher transmission voltage which to them did not appear could be met by either 230 or 287 kv. This very

Courtesy Ohio Power Company



345-kv transmission, conventional double-circuit construction, two ground wires, single conductor 1,414 MCM, 1.75-inch diameter, expanded ACSR, eighteen 5¾-inch suspension insulators.

345-kv transmission, double-circuit tower design with delta spacing and bundled conductors: two 795-MCM ACSR on 16-inch spacing, two ground wires, eighteen 5¾-inch suspension insulators.

Courtesy Ohio Power Company

conclusion was reached by the AEP System and led to the establishing in 1947, in co-operation with several manufacturers, of the Tidd high-voltage test project in Ohio. There, various aspects of transmission at voltages ranging from 265 kv to 525 kv were studied extensively over a period of several years. The resulting evaluation of the information obtained finally led to the adoption of 345 kv as the new backbone transmission voltage for the AEP System. At the present time, this voltage is being utilized or planned for installation not only on the AEP System but also in several other areas of the United States and in Canada. In addition to a total of some 2,000 circuit-miles now in operation at this voltage on the AEP and Ohio Valley Electric Corporation systems, it is now being used by Bonneville Power Administration in the Northwest, by the Commonwealth Edison Company, by Ohio Edison Company, and by the British Columbia Electric Company in Canada. Although this is the highest transmission voltage in the United States or Canada at the present time, studies are under way on a number of systems of 460 kv and even higher voltages to handle possible long-term requirements.

SYSTEM CONTROL, PROTECTION, AND COMMUNICATION

THE DEVELOPMENT of today's far-flung interconnected transmission networks obviously involved much more than simply constructing transmission lines, substations, and units of generating capacity. The solution of a great many technical problems and the development of many types of specialized equipment were required in order to mold these basic elements into effectively controlled, economically operated systems capable of supplying adequate and reliable transmission and distribution service and doing so under severe weather and other abnormal conditions. Among the problems involved were circuit interruption at new orders of magnitude of short-circuit current; protective relay schemes of greater accuracy, speed, and dependability; control, communication, and telemetering facilities for successful operation of individual systems; parallel operation of interconnected systems; and many other related problems.

The development of circuit breakers with increased operating speed and interrupting capacity has been one of the outstanding accomplishments. In 1934, the maximum interrupting ratings available up to 230 kv was 2.5 million kva and 8-cycle interrupting time was a recently brought-out improvement over the 15 cycles or more which prevailed shortly before. Spurred by the transmission and stability requirements of the Hoover Dam project in 1936, a radical advance was made in a special design of a 3-cycle 2.5-million-kva breaker for operation at 287 kv. For other duties at 230 kv and below, however, several years had to elapse before new designs with both increased interrupting capacities and higher speeds became available. In the development of these new breaker designs with much higher ratings, major field short-circuit tests supplementing laboratory development work played an important part. These included 138-kv tests up to 3.5 million kva at Philo in 1944, 230-kv tests at 7.5 million kva at

High-capacity high-altitude 300-kv line. Extra-heavy construction single-circuit line over 5,300-foot Kildala Pass, B. C., Canada. Conductor 2.32-inch ACSR to carry 600,000 kw per circuit.

Courtesy Aluminum Company of Canada

Courtesy Long Island Lighting Company

Modern dispatching center. System operations control center, Hicksville, N. Y. Underground location.

Grand Coulee in 1948, 138-kv tests up to almost 7 million kva at Philip Sporn in 1954, and finally 345-kv tests also at Philip Sporn in excess of 13 million kva in 1957. Contrasted with 2.5-million-kva ratings in 1934, circuit breakers are available today in ratings of 15 million kva at 138 kv, 20 million kva at 230 kv, and 25 million kva at 345 kv. It is notable also that design improvements have produced these high-capacity oil circuit breakers in even smaller-dimensioned tanks and lesser oil requirements than those of the 2.5-million-kva breakers 25 years ago.

In addition, substantial advances have been made in the use of mediums other than oil for breakers. For example, more than 100 breakers using compressed air as the interrupting medium are now in operation or on order in the United States, ranging in ratings from 2.5-million-kva 5-cycle opening for 115-kv designs to 15-million-kva 3-cycle ratings for 230 kv and 300 kv, and 25-million-kva 3-cycle ratings for 345 kv. At the present time, development of circuit breakers using sulfur hexafluoride gas as the interrupting medium is under way and shows promise not only of higher interrupting capacities, but also of superior performance from a maintenance standpoint.

Along with circuit breaker developments, substantial improvements have been made in protective relaying schemes for transmission systems. An early improvement was the speeding up of carrier-current differential relaying to 1-cycle operation, compared with the four cycles or more previously available. Other improvements include the introduction of a modified type of impedance relay which, combined with directional–comparison schemes with much higher current settings, permits carrying heavier overloads or swings under nonfault load conditions without unwanted tripping.

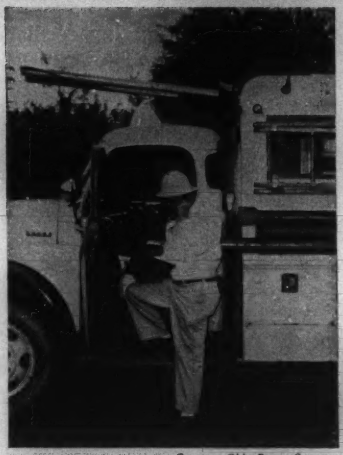
One of the developments in the transmission and protection art, which is not only outstanding in its importance but dramatic in its conception and performance, is the successful ultrahigh-speed reclosing of transmission lines by which a faulted line is opened at both ends simultaneously to clear the fault and returned to normal operation by reclosing, all in a fraction of a second. In view of the sometimes ponderous dimensions of the high-voltage switches controlling the opposite ends of a transmission line many miles in length and the high arc energy involved in a short circuit caused by a lightning flashover, the accomplishment of this opening and reclosing sequence in 1/3 to 1/4 of a second is an above-the-ordinary technical achievement. Because lightning flashover, in spite of much progress in lightning research made during the past 25 years, remains the greatest menace to transmission reliability not only throughout a great part of the United States and Canada, but in other important areas of the world as well, the significance of this technique can hardly be overemphasized, particularly in view of the increasing dependence placed upon continuous electric service in all phases of any modern industrially developed society.

Beginning with the first trial installation in 1936 on a 138-kv line with 8-cycle breakers, the use of ultrahigh-speed reclosing has been extended until, at the present time, it has become standard practice for a large portion of the industry, particularly in moderate to severe lightning areas. With the availability of 3-cycle breakers and modern carrier relaying, the art today has advanced to over-all reclosing times as low as 15 cycles (1/4 second) on 138-kv lines and 22 cycles on 345-kv lines. Performance records of 90 to 95% successful reclosure are being obtained in areas where lightning is the principal cause of line faults.

In the field of control of power system generation, frequency, etc., the operation of large complex systems and particularly interconnected groups of systems would have been greatly hampered if not rendered impracticable without developments in techniques and equipment for automatic control of frequency and tie-line loading which are in widespread use today. The need for such techniques became apparent even earlier than the beginning of this 25-year period and early applications of automatic control were made at that time on several systems, including an interconnected group of some 30 companies operating in parallel in Ohio, Indiana, western Pennsylvania, and in adjacent states to the south, all with a then-combined generating capacity of around 5 million kw.

Co-operative efforts among the operating organizations of these systems were undertaken to develop and improve automatic control techniques, and this co-operation has continued with the growth of the systems and the addition of new members to the interconnection pool until today the group comprises 104 companies operating in 29 states, with a total combined generating capacity of more than 60 million kw. Initial attempts at automatic frequency control by placing the burden on a single centrally located generating plant were quickly modified to spread the burden of frequency regulation to other stations. This approach has now expanded to the point where every important generating station in the interconnected systems group is assigned an appropriate share or "band" of generating capacity to be raised or lowered in the event of a system frequency deviation above or below a normal frequency band. The basic function of modern frequency and tie-line control is, of course, that of regulating the total generating output in each individual system in such a way that the total generation will match continuously the total system load including scheduled loads on interconnection tie-lines.

Obviously, the successful development and application of these automatic control functions along with many other requirements of modern system operation has necessitated the accompanying development of adequate communication systems. One of these functions is that of economic dispatching of generation on individual systems. This process of scheduling plant loadings for best over-all economy has been brought to varying stages of development, in some cases by continuous manual supervision from a central dispatching center using the incremental slide rule in conjunction



Courtesy Ohio Power Company

Mobile space radio equipment in electric utility line truck.

Courtesy Ohio Power Company

Microwave repeater station with steel tower.

Courtesy Westinghouse

EHV oil circuit breaker, 345-kv 25-million-kva interrupting capacity, 3-cycle opening, high-speed reclosing.

with an incremental transmission loss computer to obtain maximum economy, and in other cases by incremental loading computers installed to carry out the economic dispatching automatically. While great progress has been made, this function of system control is still in a state of development and experimentation, with various systems being proposed and a few of them under trial.

Here again adequate communication is of outstanding importance. Carrier current over power lines has been used for many years for telephone communication, relaying, telemetering, load control, etc., and is still the reliable and much-utilized medium in this field. Equipment, including transmitters and receivers, has been greatly improved in performance, particularly with respect to signal-to-noise ratio.

In many systems, however, carrier-current channels have become inadequate, both as to the number available and the quality of circuits provided. This has led to the increasing use of microwave communication systems for which suitable equipment and license authorizations became available some 10 years ago. These systems today provide high-quality voice transmission, free from atmospheric and man-made interference, and can handle a large number of channels for all communication requirements, including telemetering, system control, etc. At present, some 700 microwave stations are in service on transmission systems in this country alone. With reliability and technical performance equal to or better than any other alternative means of communication, it is expected that these systems will be greatly expanded to meet continuing growth in communication requirements.

Another form of communication, developed almost entirely within the last 25 years, is the mobile radio system by which communication is maintained between fixed centers of operation and mobile units in the field. These systems have been of tremendous assistance in the efficient deployment and supervision of manpower for all functions of utility work including construction, system operation, and both routine and emergency maintenance. Beginning with a few experimental installations 25 years ago, commercial equipment has since been developed and greatly improved, with changes from AM to FM and increased sensitivity, selectivity, etc. A recent count shows some 9,000 fixed stations and 125,000 mobile units plus a number of portable units in service today.

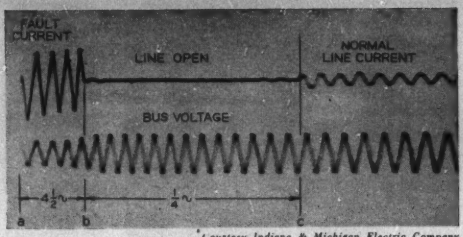
ROLE OF COMPUTERS IN THE POWER INDUSTRY

THE USE OF NETWORK ANALYZERS for power system planning had begun to a limited extent at the beginning of this 25-year period in 1934 when some three or four such analyzers had been made available. Today, some 35 of these are in use, several of the more recent designs being equipped with a large number of automatically controlled generators and other improved features to facilitate analysis of load and voltage problems on today's complex and expanding systems. In addition to their use throughout the power industry as an indispensable tool for power system planning, these analyzers in some cases have also served as effective teaching mediums in engineering schools.

Much more recently, the application of digital computers to power system planning problems has made rapid strides. For example, the powerful high-speed IBM (International Business Machines Corporation) *704* computer has been very successfully programmed

for the calculation of power flow in networks, as well as for other problems in network analysis such as stability problems, and now seems capable and perhaps destined to take over much of the job of network analyzers. The computer solution is, in fact, superior from the standpoint of economy and accuracy for load-flow problems and has been proved capable of solving other problems, such as extremely complex stability analyses which have been entirely beyond the capability of the network analyzer or any other practicable method of solution.

In system operation, digital computers are being used for certain calculations in connection with economic dispatching of power system generation as previously described. They have been of particular value in the calculation of transmission loss factors. Digital computers are being more and more extensively applied, of course, in the commercial and accounting phases of the industry and, in some cases, have done a unique job in calculating distribution transformer loading from customer billing records. Altogether, the use of digital computers appears to have opened up an extensive new field for analysis not only in system planning problems, but for many other types of decision-making problems as well.

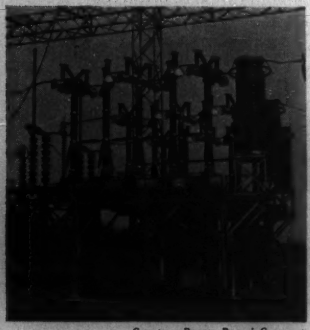


Courtesy Indiana & Michigan Electric Company

Oscillogram of ultrahigh-speed reclosing operation: (a) short-circuit current initiated (lightning flashover); (b) short-circuit current interrupted 4½ cycles later; (c) circuit reclosed after 14-cycle dead time and 18½ cycles after initial fault. Circuit restored with normal load current indicated.

Courtesy U. S. Atomic Energy Commission

Portsmouth Project, uranium diffusion plant. Peak demand (1957) 2,137,000 kw; annual consumption (1957) 17,504 million kwhr. Energy supplied by Ohio Valley Electric Corporation.



Courtesy Brown Boveri Company

Extrahigh-voltage air-blast circuit breaker, 345-kv 25-million-kva interrupting capacity, 3-cycle opening, high-speed reclosing, Lima, Ohio.

Courtesy General Electric Company

Air-blast circuit breaker, 138-kv 10-million-kva interrupting capacity, 3-cycle opening, high-speed reclosing, New York, N. Y.

DISTRIBUTION

JUST AS the great expansion in generation over the past 25 years would not have been possible without paralleling developments in transmission, similarly the efficient and economical delivery of this energy to ultimate consumers would have been severely handicapped if it had not been accompanied by the extensive and important developments in distribution which have taken place.

One of the major advances, as in the case of large power transmission, has been the development of higher distribution voltages. For example, 2,300-volt delta circuits have practically disappeared by conversion to 4,000-volt Y circuits with common neutral. At the same time, a very extensive growth has taken place in the use of the distribution voltages in the 7.2/12-kv Y class, beginning largely as a rural distribution voltage but subsequently developing into extensive use today as a highly economical voltage for urban distribution as well.

Courtesy Olin Mathieson Chemical Corporation

Aluminum reduction plant. View of potline showing 38 out of 168 pots (electrolytic cells) in a single line. Total plant load—five reduction potlines plus rolling mill—360,000 kw. Aluminum production 180,000 tons per year.

Courtesy Kaiser Steel Company

Strip mill, Kaiser steel plant, Fontana, Calif. Strip mill demand, 35,000 kw. Total plant demand, approximately 90,000 kw. Total plant annual usage, 500 million kwhr.

Although nowhere near as extensive as 12-kv Y distribution, a substantial beginning has been made in the use of 14.4/24.9-kv Y in a number of rural areas where it has proved to be practical and economical. It has also proved economical in some areas where existing 13.8-kv delta systems have been converted to 24-kv Y.

A start, at present principally in the stage of study and discussion, has been made in the use of a still higher distribution voltage, 19.9/34.5-kv Y. Trial installations at this voltage are now under way in the Northwest.

Major improvements in service reliability have been brought about by the use of high-speed circuit reclosures, not only for line-sectionalizing service, but also for use as substation feeder breakers. By this means, circuit clearing is being accomplished at three times the speed of conventional circuit breakers, along with fast restoration of service for transient fault conditions.

In the area of distribution transformers, very important developments have taken place in design improvements, giving better electrical characteristics, reduced physical size, and greater reliability. The use of grain-oriented steel, strip-wound cores, and more efficient insulating materials has practically doubled the capacity available within a given dimension, and at the same time losses and impedance values have been reduced. In one case, as an example, even a fairly recent 167-kva distribution transformer design has been replaced in exactly the same tank size with a 250-kva unit.

While underground distribution in concentrated urban areas was fairly prevalent 25 years ago, particularly in larger cities, this has been greatly expanded during this period, both in large metropolitan areas and in moderate-sized cities and towns.

The use of shunt capacitors, both switched and unswitched, has expanded to a very great extent during

Courtesy Indiana & Michigan Electric Company

Electrically heated school building. Penn Township High School near Mishawaka, Ind.; 51 classrooms; total connected load 4,816 kw.

the past 25 years, stimulated greatly by improved manufacturing methods. This has resulted in the development of progressively larger unit sizes, increasing from 15 to 25 kva, 25 to 50 kva, and most recently to 100 kva, all at the prevailing distribution voltages up to 15 kv. At the same time, in contrast to the rising costs for other equipment, the cost of capacitors in dollars per kva has actually been lowered.

Another important development, extensive in its effect, has been the almost explosive increase in the use of synthetics for cable conductor and other insulating requirements. These include polyethylene, neoprene, polyvinyl chloride, Butyl, and many others. Greatly improved characteristics in aging, resistance to chemicals, sunlight, flammability, and many others have been realized.

The use of aluminum has superseded to a very large extent the use of copper for many distribution purposes, including service drops where it is becoming almost universal practice. Aluminum is also used as a sheathing for paper-insulated cable.

Finally, in secondary voltage practice considerable use is being made of the higher-level 277/480-volt systems. It has not yet been introduced as an official stand-

ard, but its coming as an approved practice in the not-too-distant future is clearly foreshadowed.

UTILIZATION

In the past 25 years, and more especially in the period since World War II, electric energy has penetrated deeply into every phase of modern living. It is essential not only to power our industry but to perform in commerce, on the farm, and in the home the many tasks that have now come to be regarded as essential elements in our day-to-day living. The applications of electric energy range widely both in function and in magnitude; it would be difficult to conceive our society without the availability of an adequate supply of electric energy. There is little doubt that the requirements for electric energy and its applications to more and more functions will continue to expand. The growing requirements for new metals such as titanium and magnesium along with the rising demands for aluminum, all of which require electrical processes for their production, and the processing of low-grade ore such as taconite, will expand the need for electric energy in industry markedly. And beyond this, the need to expand our productivity to provide the rising standard of living that we have come to expect for a growing population in which the hours of work are falling, and the proportion of the population of labor-force age is declining, will also require the the application of substantial and increasing quantities of electric energy.

Similar considerations apply on the farm and in commerce. In the home, our rising standards of living are intimately associated with the expanding use of electric energy for the many devices that reduce the work required to maintain the home—to cook, to clean, to preserve foods, and to provide entertainment and information. In both commerce and in the home, year-

Courtesy Ohio Power Company

Modern electrified farm in Ohio has 160 acres in corn, wheat, pasture, and hay for hogs and steers. Farm equipment: food grinder, mixer, elevator, pig brooder. Home equipment: water system, two ranges, water heater, clothes dryer, deep freezer. Approximate demand 40 kw.

Courtesy Indiana & Michigan Electric Company

Modern electrically heated home, Fort Wayne, Ind., with 10-kw baseboard heating plus range, water heater, dryer. Average annual consumption 18,000 kwhr.

Neon light, ¼ watt. One of the smallest loads on a central station power system.

Courtesy Urie Brothers

Modern office building, at 750 Third Ave., New York City; 34 stories, 602,000 square feet rentable area. Total connected load: lighting 3,680 kw, motors 2,400 hp. Maximum demand (Summer 1958) 3,260 kva.

round weather conditioning is becoming increasingly important. The shopping center protected from the weather and maintaining constant temperatures throughout the year through electric cooling and heating is just at the early stages of development, and the all-electric home to provide similar comforts is also on the verge of rapid development and extension. All of this indicates a continuation of the rapid long-term increase in electric energy requirements which is likely to continue for a long time—certainly until the centenary edition of this publication appears.

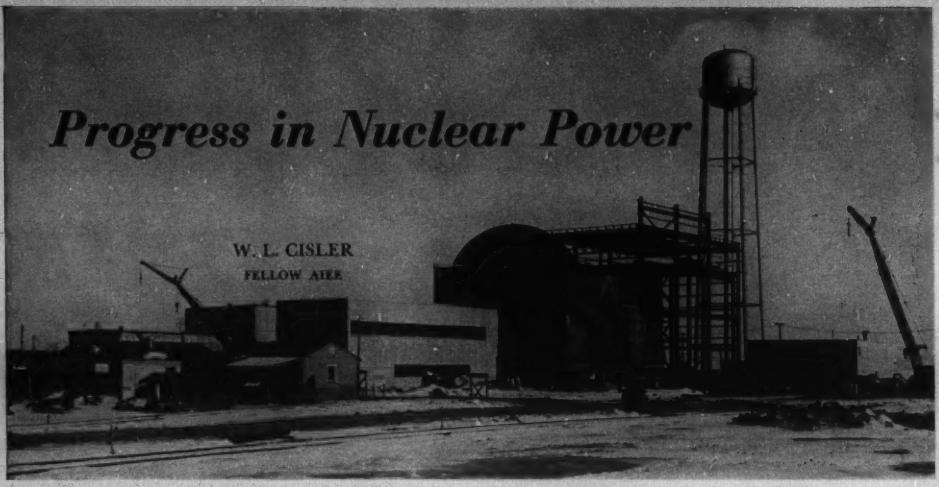
But this is not a result that can be expected to develop automatically in the natural course of events. A great deal of effort in research, development, and in utilization of new concepts and discoveries will be required on the part of many technicians, engineers, and technologists associated with the industry. Particularly in utilization, much remains to be done to develop further those devices which show promise of contributing importantly to our national productivity, welfare, and well-being. To cite just one example, an important step forward would be the development of an efficient heat storage system which would make possible the combination of an electric heat pump and solar heating system.

Although the industry in the past quarter century has made very substantial technological strides which have given the country perhaps the finest series of systems for making available to its economy an abundant and highly economical supply of electric energy, many technological challenges loom up for the quarter century ahead. In the field of atomic energy only a beginning has been made, and there still remains the finding of a solution to the many difficult problems which will make possible economic generation of electric energy by means of nuclear fission, and to make it possible for the atom to pick up some of the burden of supplying the country's ever-increasing heavy energy requirements. Much remains to be done to improve even further the efficiency of generation, transmission, and distribution and to extend the field of application of electric energy. The history of how this has been accomplished, and of how challenges have been met and responsibilities discharged by the industry and by its technicians, engineers, and technologists should make most exciting and stimulating reading in 1984.

For special hardcover Anniversary Issue coupon see p. 621

Progress in Nuclear Power

W. L. CISLER
FELLOW AIEE



Enrico Fermi Atomic Power Plant, a fast breeder type reactor, Monroe, Mich. Photo courtesy Power Reactor Development Co.

A RELATIVELY SMALL NUMBER of discoveries and inventions of tremendous consequence have shaped greatly the course of human history. In this number we would include fire, farming and herding, the wheel, the lever, the clock, the alphabet, and the zero in mathematics.

Our own age has the distinction and responsibility for one of the greatest discoveries of all—nuclear energy. And oddly enough, its achievement was a surprise to almost everyone.

The hero, once again, was that all-too-frequently underrated activity, the pursuit of knowledge for its own sake. Roentgen's discovery of X rays in 1895 was followed quickly by Becquerel's discovery of radioactivity and the isolation of radium by the Curies. Then came Einstein's equation for the equivalence of mass and energy, Planck's quantum mathematics, and much eager research into the structure of the atom. For several decades, the mass–energy relationship was a matter of considerable humor to the general public. Many scientists considered it as having philosophical rather than practical implications.

Nevertheless the tempo of discovery increased, culminating in 1939 in unmistakable proof that the uranium nucleus is, in some cases, unstable and may, after neutron capture, divide into two nuclei of roughly equal size. It was predicted that the fragments must fly apart with high velocity, increasing the random molecular activity that we know as heat.

This was intensely interesting to scientists, yet a seemingly impossible distance from any plan for developing a useful energy source. However, it was thought—and soon proved—that neutrons are emitted during fission. This created the distinct possibility that the fission process could be self-reproducing in a sort of chain reaction.

During 1940, sufficient data were verified to make it quite likely that such a chain reaction was not only possible but that it could be controlled. On December 2, 1942, at the University of Chicago, after extraordinary theoretical and technological endeavors, a self-maintaining chain reaction was begun and controlled for the first time in history. At that moment we entered the Atomic Age.

THE MILITARY ATOMIC DEVELOPMENT PROGRAM

UNFORTUNATELY, these superb achievements of the human spirit were brought to fulfillment in the atmosphere of a global war for survival. The United States and Great Britain together launched a crash program of nuclear weapons development under a cloak of absolute secrecy. Except for the military and a handful of scientists, the world was unaware of the new energy source until Hiroshima and Nagasaki. It has been very difficult since then to correct the general public's impression that the atom is a danger rather than a boon to mankind.

During the war the Manhattan Engineer District, the U.S. Army's wartime operator of the weapons development program, learned much that could be applicable to the peaceful use of nuclear energy. After the war, the project personnel turned their thoughts in that direction, with the approval and support of the military organization. The Daniels Pile Project at Oak Ridge, Tenn., in 1946 was one of many such demonstrations.

EARLY DAYS OF THE ATOMIC ENERGY COMMISSION

THIS PERIOD was brief, however. The United States Congress conducted extensive studies in 1945 and 1946 concerning the proper method for administering atomic matters. Largely as a result of the continued unsettled

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international situation, the Atomic Energy Act of 1946 provided that a civilian Atomic Energy Commission (AEC) would have complete control over such activities. The Commission was directed to develop atomic energy for peaceful purposes, but industry was prohibited from engaging in atomic affairs except under contract with the Commission.

On January 1, 1947, the AEC took over in an atmosphere of renewed world tension. But rather than setting in motion a relaxation of security regulations and a program for peaceful development, the Commission reluctantly found itself primarily in the weapons business.

These crucial years culminated in the Korean conflict in 1950. However, even while this was going on, the desire to develop the peaceful atom persisted and found expression in some of the important work of the Commission, leading to the AEC Five-Year Reactor Development Program.

In the meanwhile, industry shared the scientific world's increasing interest in the new energy source, which obviously held great promise for a world consuming its nonrenewable fossil fuels at an ever-increasing rate. As far back as December 1945, the Association of Edison Illuminating Companies organized a committee to investigate the probable effect of nuclear energy on the electric power industry. It was not easy in those early days to form an adequate estimate of the situation, partly because the basic technology was almost completely undeveloped and partly because security restrictions made the task of theoretical evaluation almost impossible.

In October 1947 the AEC, in response to suggestions from the electric power industry, established the Industry Advisory Group with James W. Parker, then president of The Detroit Edison Company, as its chairman. Subsequently in its report to the Commission, the committee urged that industry be given greater opportunities in nuclear development.

Further AEC-sponsored studies by several other groups pointed out that nuclear power was feasible and could, in time, become competitive with conventional power generation.

THE ATOMIC ENERGY ACT OF 1954

In 1954, Congress amended the Atomic Energy Act of 1946, allowing maximum availability of classified information on a need-to-know basis, and permitting fuller participation by industry in the field of nuclear power development, including the ownership of nuclear facilities. The new law gave the Commission the responsibility to see that "the development, use and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living and strengthen free competition in private enterprise."

Many realized, during these early years, the importance of advancing nuclear technology by relating it, in as many ways as possible, to the dynamic capabilities of American industrial enterprise. Before Hiroshima, the Manhattan Engineer District began the practice of using academic and industrial contractors in the development and operation of nuclear facilities. Later, the AEC foresaw the need for the ultimate development of a nuclear industry and maintained a policy of broadening private participation. Uranium mining, prospecting, and milling activities were encouraged to the extent that by 1955 the Commission could announce that the United States had become one of the leading uranium producing nations of the world. Encouragement was also given to the private manufacture of radiation detection instruments and the manufacture and distribution of radioisotopes for research, medical, industrial, and other uses.

Over the years the task of the Commission has been, under the frequently limiting circumstances of security, to encourage industrial development, to disseminate classified information as needed to cleared personnel, to extend declassification, to provide new industry with material and services, and to regulate these endeavors in the interest of health, safety, and national security.

Certainly everyone who has served the Nation, either in the Commission or on the Joint Committee on Atomic Energy, would affirm that this has not been an easy task. The men charged with the responsibility have been required to consider not only the traditions and practical realities of our American system, but also many complex areas of science and technology, of law and finance, of economics and business management and, most importantly, of politics and international relations.

Since 1954, an extensive atomic energy industry has been developed in our Nation. One section buys and uses atomic energy products. Another designs, builds, and operates research and power reactors, and provides additional services. All this makes up a new and highly technical industry with the problems, the occasional failure and more frequent successes that go with incentive enterprise. As a result, American industry has grown in stature with all this new experience and the Nation's nuclear energy program has been correspondingly broadened and advanced.

INDUSTRY ASSOCIATIONS AND SOCIETIES

To assist enterprises in finding their way in this fast-growing field, the Atomic Industrial Forum, Inc., was established in April 1953. Its membership now comprises approximately 515 companies, large and small, engaged in the atomic energy business, and 1,700 individual businessmen, educators, scientists, technologists, and others who have interests in various aspects of atomic matters.

The Forum serves as a clearing house of information and continues to be useful in keeping management and other people well informed on new developments, requirements, products, and opportunities. These aspects of management control and direction are highly important to the long-term interests of our scientific and technological achievements in the nuclear energy field.

The corresponding organization in the scientific and technical field is the American Nuclear Society, Inc.

organized in 1955, which provides scientists and engineers with many informative contacts in their field of interest. Through such an organization of eminent professional standing, the development of nuclear arts is greatly assisted.

Another organization important to nuclear progress is the Fund for Peaceful Atomic Development, Inc., comprising nongovernmental individuals eager to help other nations in the task of adapting nuclear energy for peaceful purposes. It originated in the United States. Similar organizations have been established in Japan, Belgium, Luxembourg, and Switzerland. They provide scholarships and fellowships under which people of promise and talent can visit other nations to study atomic matters. The Fund organization in the United States has sent consultants to a considerable number of countries to give advice on both the broad and specific areas of nuclear development.

From this brief sketch, we can see something of the general outlines of how industry, science, and government have been learning to work together effectively. Let us now turn to what perforce must be an incomplete account of progress in power reactor development within this framework in the United States.

POWER REACTOR DEVELOPMENT

In the spring of 1954, the work done by the Atomic Energy Commission in its facilities began to show encouraging progress. At least three operating reactors had been built and others were under construction, particularly the *Nautilus* and *Seawolf*. The AEC announced a Five-Year Reactor Development Program for the national laboratories. The five most promising reactor concepts were singled out for particular emphasis: (1) Pressurized water; (2) Boiling water; (3) Sodium-cooled thermal; (4) Fast breeder; and (5) Homogeneous.

The AEC's reactor development program was supplemented in 1955 by the Power Reactor Demonstration Program, under which privately owned or publicly owned organizations would assume the risk for construction, ownership, and operation of nuclear power plants, while the Commission would provide, under contract, specified research and development work, and waive a portion of the nuclear fuel charges.

Two rounds of invitations were announced in 1955. In 1957, there was a third round of invitations, although the Commission has been ready at all times to entertain discussions on projects of merit. To date, the Commission has also recognized three projects proposed by private industry to be carried out without any special assistance from the Commission and therefore on the basis of completely private financing (see Table I).

Our Nation has a long-range rather than immediate incentive for the development of nuclear power and, therefore, can engage in a broader program than some other nations. We have adequate supplies of heavy water, helium, hafnium-free zirconium, and of all types of nuclear materials, including enriched uranium. We also have the extensive laboratory and industrial facilities needed for a broad plan of development.

Table I. Power Demonstration Reactor Program Projects

Type	Sponsor
First Round	
Fast Breeder	Power Reactor Development Company, Monroe, Mich.
Pressurized Water	Yankee Atomic Electric Company, Rowe, Mass.
Sodium Graphite	Consumers Public Power District, Hallam, Nebr.
Second Round	
Aqueous Homogeneous	Wolverine Electric Cooperative, Hersey, Mich. (Canceled)
Boiling Water	Rural Cooperative Power Association, Elk River, Minn.
Organic Moderated	City of Piqua, Ohio
Sodium Heavy Water	Chugach Electric Association, Anchorage, Alaska (Canceled)
Third Round and Thereafter	
Advanced Boiling Water	Pacific Gas and Electric Company, Humboldt Bay, Calif.
Aqueous Homogeneous	Pennsylvania Power & Light Company—Baltimore Gas and Electric Company (Canceled)
Boiling Water	Northern States Power Company—Central Utilities Atomic Power Associates, Sioux Falls, S. Dak.
Gas-Cooled	Philadelphia Electric Company—High Temperature Reactor Development Associates
Gas-Cooled Heavy Water	East Central Nuclear Group—Florida West Coast Nuclear Group
Pressurized Heavy Water	Carolina–Virginia Nuclear Power Associates, Inc., Parr Shoals, S.C.
Other Projects (Unassisted)	
Boiling Water	Commonwealth Edison Company—Nuclear Power Group, Dresden, Ill.
Boiling Water	General Electric Company–Pacific Gas & Electric Company, Vallecitos Plant, Pleasanton, Calif.
Pressurized Water	Consolidated Edison Company of New York, Inc., Indian Point, N. Y.

The availability of special nuclear materials has permitted us to emphasize concepts requiring enriched uranium, leading to relatively high-power density cores. The long-range value of some of these concepts may be debatable, but the very wide range of information so derived will be of great value.

Let us look at some of the dramatic highlights of our progress to date.

PRESSURIZED WATER POWER REACTORS

In these reactors, water is used for both moderating (slowing down) the neutrons and for transporting the heat out of the reactor so that it can be put to useful work. The pressure, usually 1,500 psig (pounds per square inch, gauge) or more, permits the water to carry more heat and reach higher temperatures without boiling. Such reactors can utilize slightly enriched, up to fully enriched, uranium or plutonium as the fuel. A high degree of fuel enrichment can be used to achieve a high heat rate in a relatively small space. This can be useful in designing "package" power plants for naval or military use. The examples to date have demonstrated a high degree of reliability for this very promising concept.

The Nautilus. Development had progressed sufficiently far in 1951 to permit the construction of the STR-Mark I, the land-based prototype for the *USS*

Nautilus reactor. This first produced power in 1953. The construction of STR-Mark II, the reactor for the *Nautilus*, was practically on the same schedule as the Mark I version.

Since launching in 1955, the *Nautilus* has shown the world in dramatic fashion that a properly designed reactor can operate dependably and without hazard even under the intensive requirements of submarine service. This was the first reactor in the world built to perform a specific job outside the laboratory.

It would be impossible to overemphasize how well the reactor has fulfilled this pioneer assignment—a remarkable technological achievement for Vice-Admiral Hyman Rickover and his associates. The feats of the *Nautilus* and its intrepid crew have begun a new saga in American naval history.

The AEC–Duquesne Light Company Shippingport Atomic Power Plant. The Shippingport facility, built as was the *Nautilus* under the direction of Admiral Rickover, resulted from the combined endeavors of the AEC, the Westinghouse Electric Corporation, and the Duquesne Light Company. This was the first project completed under the AEC Five-Year Reactor Development Program.

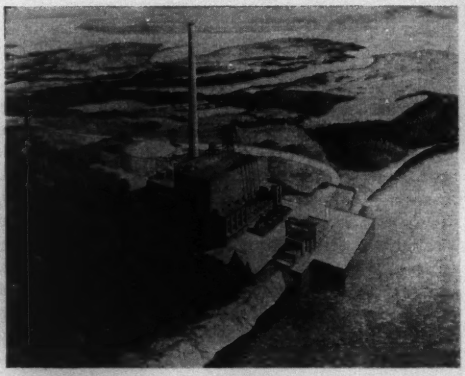
It went critical on December 2, 1957, and reached full power output (60,000 kw) within 3 weeks. Its performance has been as good or better than expected. Operating costs are high, around 56 mills per kwhr, partly because the development expense is included in the capital investment and particularly because of the expensive fuel cycle, the best answer available at the time when fuel decisions had to be made.

Army Package Power Plant. The Army Package Power Reactor was the first application of the pressurized water concept to a small land-based power plant. It was placed in operation in April 1957 at Fort Belvoir, Va., generates 1,855 kw, and has shown remarkable stability under severe test conditions. It holds considerable promise for easy assembly and operation in remote locations, yet further development to reduce transportation problems will be required.

Atomic Plant at Indian Point. Modification and advances in the pressurized water approach are represented by the plants under construction by Consolidated Edison Company of New York, Inc., and by the Yankee Atomic Electric Company.

Consolidated Edison has a contract with The Babcock & Wilcox Company for the design of a 275,000-kw plant at Indian Point on the Hudson River, about 24 miles north of New York City. Initially, it will be fueled with uranium-235, but it is designed to accommodate a thorium–uranium-233 fuel cycle. Its potentially inexpensive fuel cycle holds promise of being commercially attractive. Other features differing from the Shippingport design include a separate oil-fired superheater to raise the steam temperature to 1,000 F. The reactor will provide the heat energy for the generation of 163,000 kw of electric power with the super-

Pressurized water reactor. Shippingport Atomic Power Plant, near Pittsburgh, Pa.



Pressurized water reactor. Artist's conception of plant being built by Consolidated Edison Company of New York at Indian Point, located on Hudson River north of New York City.

Pressurized water reactor. Yankee Atomic Electric Company, Rowe, Mass.

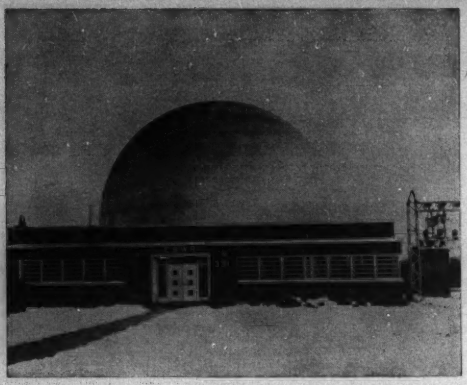


Photo courtesy Argonne National Laboratory

Experimental Boiling Water Reactor, Lamont, Ill.

heater doing the rest. The plant is being built entirely with private funds and is scheduled for completion in 1961.

Yankee Atomic Power Plant. A group of New England power systems has organized the Yankee Atomic Electric Company to build a 134,000-electric-kw plant at Rowe, Mass., working with the Westinghouse Electric Corporation. Completion is scheduled for 1960. This plant may be regarded as a second generation pressurized water reactor project based on Shippingport, but with a somewhat different fuel system. The fuel is slightly enriched uranium in the form of uranium oxide pellets. Over-all design and construction is being done by Stone & Webster Engineering Corporation.

Fuel Cycle Costs. The extent of progress in fuel cycle economics for pressurized water reactors can be seen by a comparison of fuel costs as estimated by the three large plants we have been discussing. Mills-per-kwhr costs for Shippingport fuel range from about 33 to 20, depending upon present operating methods for the high estimates and assuming the lower range in the event of greater burn-up and higher electric output.

On the other hand, the later design estimates for Indian Point come out to just under 7 mills per kwhr, and the Rowe plant comes down to 5 mills per kwhr. Obviously, fuel cycle technology is going to be an important factor in the endeavor to make nuclear power competitive with conventional plants.

BOILING WATER REACTORS

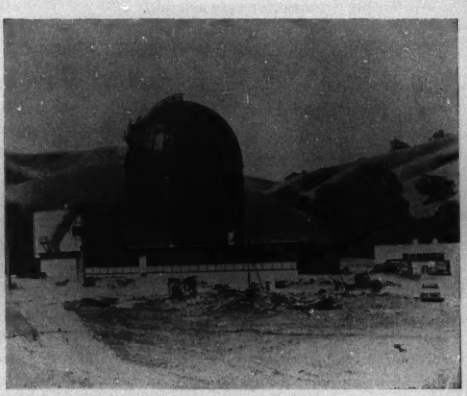
BOILING WATER REACTORS also use water as a moderator and coolant, but permit it to boil in the reactor core, making it possible to send the steam directly to the turbine. If the reactor builds up heat output to the point where steam voids replace the water in the core, the moderating effect is diminished and with it the fissioning activity. This makes the boiling water reactor inherently very stable. It is believed by some who are engaged in boiling water reactor development that attractive costs will be reached in a few years. The boiling water concept will have many possible applications here and abroad, particularly in the 50,000- to 200,000-kw range.

Experimental Work. Research got under way on this concept in 1953 with the construction of Boiling Reactor Experiment No. 1, commonly known as BORAX-1, under the direction of Dr. Walter Zinn at the Idaho Testing Station of the Argonne National Laboratory. BORAX-1 was built along relatively simple experimental lines, demonstrating the stability and inherent safety characteristics of this reactor system. In July 1954, it was intentionally put out of service by a test to determine its reaction to extreme conditions beyond the limits of stability.

BORAX-2 was built in the same year and modified into BORAX-3 in 1955. On July 17 of that year, the reactor served as the exclusive source of electric power for the town of Arco, Idaho, for about an hour, another "first" in history. BORAX-4 went critical in 1956, completing the cycle of boiling reactor experimental setups.

A direct outgrowth of this work was the Experimental Boiling Water Reactor (EBWR), a part of the AEC Five-Year Reactor Development Program, which achieved criticality at the Argonne National Laboratory on December 1, 1956. Although designed to have a thermal capacity of 20,000 kw, the power output was successfully raised to 60,000 kw. At present, some changes are being made with the expectation that the heat output can be increased to 100,000 kw.

The lesson to be learned from this is that the performance of the boiling water reactor is stable and self regulating. Once a critical mass is properly established, the reactor heat output depends mainly upon metallurgical limitations and our ability to extract the heat. Improve-



Vallecitos Boiling Water Reactor, near Pleasanton, Calif., shown under construction, is now completed. It was built by General Electric in cooperation with the Pacific Gas & Electric Company.

An example of the boiling water reactor is the Dresden Atomic Power Plant of the Commonwealth Edison Company–Nuclear Power Group, Inc., located near Joliet, Ill.

ments in this direction will do much to help us to achieve economical nuclear power.

Vallecitos and Dresden Projects. The Vallecitos Boiling Water Reactor, built by the General Electric Company as a prototype for the Dresden station described next, has an output of 5,000 electric kw. It went critical in August 1957 and operates under Power Reactor License No. 1 of the AEC. The reactor is connected with a turbine–generator owned and operated by the Pacific Gas & Electric Company. It, too, has demonstrated its ability to operate with a heat rate far above the original design.

In July 1955, the Commonwealth Edison Company–Nuclear Power Group contracted with the General Electric Company to build the Dresden Nuclear Power Station near Joliet, Ill. When completed toward the end of 1959, it will be the first commercial-size boiling water reactor plant, having an output of 180,000 electric kw. Both Vallecitos and Dresden projects have completely private financing.

Other Boiling Water Reactor Projects. Several other boiling water projects are in the design and development stage. The Northern States Power Company–Central Utilities Atomic Power Associates are working in co-operation with the Allis-Chalmers Manufacturing Company on a controlled recirculating boiling water reactor scheduled for 1962. It will have an output of 66,000 electric kw. It was recently announced that nuclear superheat is being considered. Location will be Sioux Falls, S. Dak.

Pacific Gas & Electric Company is working with General Electric on an advanced boiling water design to produce at least 50,000 electric kw. This is the Humboldt Bay project and will be built at Eureka, Calif., scheduled for completion in 1962.

In June 1958, the AEC signed a contract with the Nuclear Products–Erco Division of ACF Industries, Inc., to develop and build a demonstration nuclear plant at Elk River, Minn. The Rural Cooperative Power Association will provide the site, the turbine–generator facilities and buy the steam during the contract period of 5 years. This will be a test operation of a closed-cycle boiling water reactor plant producing 22,000 net electric kw. The plans for the fuel cycle specify a mixture of thorium and uranium oxides.

LIQUID METAL THERMAL REACTORS

LIQUID METAL COOLED REACTORS are being developed both as thermal and as fast breeder reactors. Sodium, which is used in most instances, has definite advantages as a heat transport agent without the need for high pressures associated with pressurized water power reactors. Since sodium does not act as a moderator, moderation must be accomplished with another material such as graphite; or, as in the case of the fast breeder, sodium is used to avoid slowing down the neutrons to thermal velocities.

Sodium Reactor Experiment. Although graphite reactor technology goes back to 1942, sodium technology is of more recent development. They were brought together in the Sodium Reactor Experiment (SRE) in 1957. Build for the AEC by Atomics International, a division of North American Aviation, Inc., as a part of the Commission's Five-Year Reactor Development Program, the plant is designed to produce 20,000 thermal kw and 6,000 electric kw. The conventional steam turbine–generator equipment was installed and is owned and operated by the Southern California Edison Company. Tests of this reactor are still in progress but much has been learned about sodium–graphite reactor technology through the use and modification of this experimental facility.

SRE was built as a prototype for the sodium graphite reactor (SGR), a commercial-size sodium-cooled

Sodium Reactor Experiment at Canoga Park, Santa Susana Mountains, Calif. The AEC's experimental reactor was built by Atomics International, with electric generating equipment installed by Southern California Edison Company.

Photo courtesy Lookout Mountain Laboratory

Experimental Breeder Reactor No. 1 at the National Reactor Testing Station, Arco, Idaho, operated by the Argonne National Laboratory.

graphite-moderated plant envisioned by the AEC in its long-range program. Actually, SGR may or may not be built.

Projects in Development. An advanced version of the concept, however, is in the design and development stage for the Hallam plant of the Consumers Public Power District of Nebraska, with operation scheduled for 1962. Atomics International is designing the plant for the AEC using data from SRE experience as well as recent advances in fuel and component technology. The Power District will provide the site, generating facilities (100,000 kw), share in the costs of building the nuclear part of the plant, and then operate the entire plant for 5 years. The plant will initially produce 75,000 electric kw.

At Anchorage, Alaska, a plant was planned to use sodium for heat transfer and heavy water for moderation. This was the Chugach plant of 10,000 electric kw scheduled for 1962 for the Chugach Electric Association. The Commission contracted with Nuclear Development Corporation of America for the research, development, and preliminary design. This project was recently canceled.

FAST BREEDER REACTORS

REACTORS can be classified as burner-uppers, converters, and breeders. For special military applications, the burner-upper achieves very high heat output in very little space. It utilizes highly enriched fuel—fissionable uranium-235 or possibly plutonium; consequently, little plutonium is produced. The converters, fueled with natural or somewhat enriched uranium, produces 60 to 80% of plutonium in relation to burn-up. In much the same way, fertile thorium (Th-232) can be transmuted into fissionable uranium-233.

AEC Experimental Breeder Reactor No. 1. Of all reactors, only the breeder produces more fissionable fuel than it consumes. In 1947, when the Commission approved the Argonne project to build Experimental Breeder Reactor No. 1 (EBR-1), it was believed that world resources of uranium were extremely limited, and that any substantial power industry would have to find a way very soon to use the much more abundant isotope U-238 by turning it into plutonium. This is what the large thermal reactors at Hanford (Wash.) and Savannah River (S.C.) were doing, but at low temperatures and at a net fuel loss. Breeder reactors, on the other hand, would produce useful heat, and new fuel as well, at a net fuel gain. Although we now know that the world's uranium reserves are substantial, the breeding principle will inevitably become very important in a large-scale nuclear power economy.

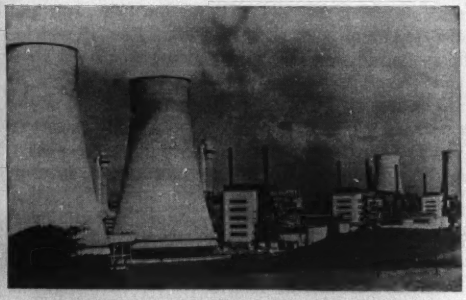
EBR-1 went critical in August 1951 and on December 22 of that year produced the world's first electricity from atomic energy. Operating on its first core from 1951-54, the reactor demonstrated that breeding was feasible. Further experiments were performed with a second core (Mark II) until November 1955 when an experimental power excursion caused a fuel element meltdown. Operation with a redesigned Mark III core that avoided excessive inward bowing of the fuel elements began in November 1957. With this core, EBR-1 has performed very well, providing valuable data on breeder reactor stability and other essential questions.

AEC Experimental Breeder Reactor No. 2. EBR-2 is now under construction at the National Reactor Testing Station at Arco, Idaho, and will produce about 17,500 kw, serving in part as a prototype for the 50,000-kw power breeder reactor in the AEC's long-range planning. It is expected to reach full power in 1960 and help in the solution of the fuel cycle problem and other matters. It will first be fueled with uranium and later operate on plutonium. An integrated fuel processing and fabrication plant will be part of the facility.

Breeder reactor being built by the United Kingdom at Dounreay, Scotland.

Los Alamos Molten Plutonium Reactor Experiment. Meanwhile, the Los Alamos Scientific Laboratory is developing the concept for a molten plutonium reactor experiment (LAMPRE-1). It will be a small-scale fast reactor and is not designed to produce electricity when it goes into operation late in 1959. Its fuel is highly active metallurgically and, therefore, the reactor will need a structural material that has a high melting point and is inert to molten plutonium alloys and the sodium coolant. Successful fabrication and operation will be an important step forward in fast reactor fuel technology.

Enrico Fermi Atomic Power Plant. The Enrico Fermi Atomic Power Plant at Monroe, Mich., is the only reactor of this type being developed, designed, and built by private industry, in co-operation with the Atomic Energy Commission. Research, development, and conceptual design are the responsibility of Atomic Power Development Associates, Inc. (APDA), a nonprofit organization composed of 42 member companies. The nuclear facilities of the plant are being designed and built by Power Reactor Development Company (PRDC), another nonprofit membership company having 21 members. The funds needed to meet the expenses of APDA and PRDC are contributed by the member organizations. The Detroit Edison Company is building the generator facilities and will buy the steam from PRDC. The plant will have a net electrical output of 100,000 kw and is scheduled for completion in the fall of 1960.



Gas-cooled reactors of the United Kingdom at Calder Hall.

The United Kingdom Dounreay Fast Breeder Project. The British selected the breeder reactor as the second type for development in their program. The 20,000-kw Dounreay (Scotland) reactor, now being prepared for operation, is an important item in the breeder reactor development program. Engineers and scientists of the Dounreay and Fermi projects are co-operating extensively.

GAS-COOLED REACTORS

GAS-COOLED POWER REACTORS can be designed to operate gas turbines directly or to make steam. Because the latter has lower temperature requirements, the materials problems have been less severe, thus creating opportunities for development at a fairly early date. This was the decision of our British friends, who have been the outstanding pioneers in gas-cooled reactor technology. Calder Hall is one of the important milestones of nuclear progress.

Gas-cooled power reactors were among the first studied in the United States. The Daniels Pile Project mentioned earlier was a reactor of this type. The concept was not pursued in this country for some time because it did not seem to have any special advantages in terms of our interest in enriched fuels, higher temperatures, more compact designs, and coolants with much higher heat removal capability. As will be discussed later, however, it has been the major concept in the British program.

Research and experimentation have been pursued by the United States along the high temperature approach on the Aircraft Nuclear Propulsion Program, the Army Reactors Program, and also in the interests of the Maritime Administration of the Department of Commerce.

High-Temperature Power Concept. Recently, when fuel elements were developed to operate at a very high temperature, the gas-cooled reactor concept revealed new civilian possibilities which are being followed up promptly. Construction of a gas-cooled reactor was recently announced by the Philadelphia Electric Company and High Temperature Reactor Development Associates, an industry-sponsored corporation.

Its proposed design by General Atomics is somewhat different from Calder Hall in that it is more compact, uses helium in place of carbon dioxide as a coolant, and will have enriched fuel. Its sponsors are optimistic about its economic potential and expect to gather much useful data on high-temperature technology that can be applied to other reactor concepts as well. The plant will have an output of 30,000 to 40,000 electric kw.

OTHER REACTOR TYPES

THE COMPREHENSIVE American program includes a number of other promising concepts on which it is yet too early to estimate either their performance characteristics or commercial application.

Among these are the fused salt and aqueous homogenous approaches being explored by Oak Ridge National Laboratory; the gas-cooled, heavy-water-moderated reactor being developed by the Florida West Coast and East Central nuclear groups; the liquid-metal-fueled reactor (LMFR) being developed by the Brookhaven National Laboratory in co-operation with The Babcock & Wilcox Company; and the organic-moderated reactor under development by Atomics International under contract with the AEC for the City of Piqua, Ohio.

PROGRESS IN OTHER NATIONS

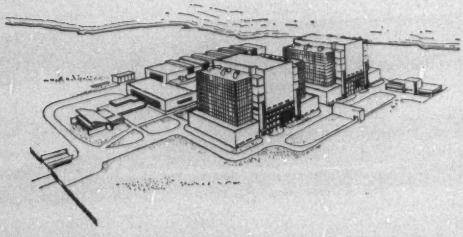
MANY COUNTRIES of the world are engaged in atomic power development, but the most active programs are being pursued by the United Kingdom, Canada, France, Belgium, Italy, Japan, and the Union of Soviet Socialist Republics.

In 1953, President Eisenhower proposed the "Atoms for Peace" Plan, which made our already highly developed nuclear energy technology and the supporting industrial complex available to other nations for peaceful applications. The Plan was strongly endorsed in 1955 by our extensive participation in the United Nations International Conference on the Peaceful Uses of Atomic Energy at Geneva, Switzerland. This was followed by a second conference in 1958 that produced an enormous quantity of information concerning the peaceful uses of the atom. Both conferences were truly international in scope, with many nations making significant contributions.

There has been close co-operation and exchange on a bilateral basis among many nations of the Free World, a very promising United States–Euratom program begun, the establishment of the International Atomic Energy Agency, special reactor technology training programs for personnel from other nations, and an increase in person-to-person contacts with the USSR. The Fund for Peaceful Atomic Development has been active in the exchange of information.

Although national interests are, as always, very much in the spotlight, the energy needs of all nations in the cause of human betterment may give men of good will the leverage they need in developing the mutuality essential to a lasting peace.

United Kingdom. The apparent need for nuclear power at an early date and the limited facilities and resources available for developmental programs caused the British to concentrate on producing power plus plutonium in large stations using carbon dioxide cooled, graphite-moderated, natural uranium reactors. In the circumstances, this was an understandable decision and one that the nation has implemented in a most dramatic fashion. Calder Hall is certainly an important event in the Free World's development of nuclear technology, an achievement that inspired all of us with admiration and a healthy sense of technical competition in a great cause.



Artists conception of two graphite–carbon dioxide units under construction by the United Kingdom at Bradwell, England. Total electric capacity, 300 mw. Completion is scheduled for 1961.

By the end of 1959, the British will have eight reactors of this class in operation, four at Calder Hall and four at Chapelcross, each producing 46,000 electric kw. It has been estimated that these installations will save the equivalent of about a million tons of coal a year.

In February 1955, the British announced a program to construct atomic power plants, which might be considered as second generations of Calder Hall, with a total capacity of about 5 million electric kw, to be in operation before the end of 1965. Subsequently, because the coal situation appeared to be less acute than originally believed, and in order to make the best use of available capital, personnel, and materials, there has been an extension in the completion dates. At present, four large plants are under construction: Berkeley (275 mw); Bradwell (300 mw); Hunterston (300 mw); and Hinkley Point (500 mw). Sites have been chosen for Trawsfynydd (500 mw); Dungeness (500 to 550 mw); and Sizewell (650 mw).

The British recognize that the present design of the gas-cooled reactor has severe limitations with respect to fuel cycle performance and temperatures. They have studies under way which are expected to lead to an advanced type of gas-cooled reactor.

In looking to the longer range future, Britain undertook the development of the breeder reactor as a definite goal. This led to the design and construction of the Dounreay Fast Breeder Reactor (20,000 electric kw) in northern Scotland. As of February 1959, the construction was essentially complete. Initial nuclear operation is scheduled for April 1959.

Canada. Our Canadian friends have long specialized in natural-uranium heavy-water-moderated reactors, and have developed much of the technology pertinent to this approach at Chalk River. They are now developing a power plant along these lines showing great promise, particularly because it can use natural uranium in the form of an oxide.

France. The program of the Commissariat à L'Énergie Atomique of France includes the plutonium-producing thermal reactors nearing completion this year at Marcoule with a net capacity of 60,000 electric kw.

Électricité de France (EDF) began a reactor construction program in 1955. A gas-cooled natural-uranium graphite-moderated power plant (EDF-1) at Chinon will be in operation later in 1959, designed to produce 60,000 electric kw. EDF-2 at the same site and ready for operation 18 months later, will produce about 160,000 electric kw net. A third plant of about 250,000 electric kw is now in the planning stage.

The EDF program provides for the building of a new nuclear plant every 18 months, doubling the installed nuclear power capacity every 3 years. In this initial program, each plant will be different from its predecessors to provide experience on a variety of promising con-

cepts. No duplication of a specific design is expected for several years. The French are interested in reactors of the breeder type and have begun the initial steps in a breeder reactor development program.

Belgium. The Belgian Congo was the main source of uranium during World War II and subsequent years until economically recoverable deposits were discovered in many other areas of the world. As a direct result, Belgium undertook an aggressive atomic power development program shortly after the war's end.

Because Belgium still has substantial resources of coal, it has adopted a program of study, research, and development rather than an immediate construction program. It now has an outstanding atomic center at Mol, and its scientists and engineers are engaged in detailed studies of all promising reactor types.

As a supplement to these activities, Belgium has purchased a 12,000-kw pressurized water reactor power plant from the Westinghouse Electric Corporation. This plant is now under construction at the Mol atomic center and should be ready for operation in late 1959 or early 1960.

As a member of Euratom, Belgium hopes to undertake one or more of the major atomic power plant projects planned by that group. The nation expects to build a fast breeder plant by 1967.

Italy. The growth of industry in Italy is accentuating the seriousness of that nation's energy and fuel situation. The chief power source has been hydroelectric in the Alps and Apennines, with some help from geothermal power. Most of the economic hydraulic power sites have been developed. The recent discovery of limited amounts of oil and natural gas has brought forth energetic plans for development, but it is not expected that these resources will have a great long-range effect. Italy faces an ever-growing problem of importing fuel to match industrial progress—a problem that the atom may greatly ease.

Italy is engaged in several projects intended to provide extensive experience in atomic power, using technology developed in other countries. There is a contract with a manufacturer in the United Kingdom for a 200,000-kw gas-cooled graphite-moderated natural-uranium reactor plant to be built at Latina, 40 miles south of Rome, with completion scheduled for 1962. This plant will be similar to the Bradwell project in England.

The International General Electric Company has a contract with the Societa Elettronucleare Nazionale to build in southern Italy a 150,000-kw boiling water nuclear power plant generally similar to the Dresden, Ill., plant being built by the Commonwealth Edison Company–Nuclear Power Group. It will be, in many respects, a second generation of that design.

The Westinghouse Electric International Company has a contract with Edisonvolta S.p.A., of Milan, for a 134,000-kw pressurized water power plant that will be based upon the design for the Yankee Atomic Electric Company at Rowe, Mass.

Euratom. The Euratom program is a very important extension of co-operation across international boundaries in Western Europe. Six countries—Belgium, France, Italy, Luxembourg, The Netherlands, and West Germany—have agreed to pool at least a part of their atomic development efforts and have worked out a program for the construction of approximately six atomic power plants with a total capacity of 1 million kw, hopefully by the end of 1963.

The capital cost of the program, exclusive of fuel, is estimated at $350 million. Euratom has entered into an agreement under which the United States will provide up to $50 million toward research and development projects and up to $135 million in the form of long-term credits to cover the capital costs for the construction of atomic power plants. In addition, the United States will guarantee the integrity and performance of the fuel elements for a 10-year period.

It is probable that some of the plants constructed in the Euratom program will be second generations of plants now being built in the United States.

Japan. Here, the study of the peaceful use of nuclear energy began officially in 1954 and is being undertaken by government agencies and industry. Initially, most of Japan's work will be based upon development activities in the United States, United Kingdom, and other nations. Quite properly, they are finding their most logical approach in surveying present technology as the basis for their own research and development.

The demand for electric power is increasing about 10% a year and is expected to continue to grow at this rate for many years. Since Japanese hydroelectric resources have been well developed, nuclear and conventional thermal plants must be installed to meet the increasing demand for electric energy.

Conventional plants burning domestic coal and imported oil produce power today for about 12 mills per kwhr. This is expected to increase in the future. Because Japan appears to have limited fuel resources, it will probably be one of the first countries where nuclear power will be economically competitive with conventional power.

The long-range program provides for about 600,000 kw of nuclear power capacity by 1965 and 7 million kw by 1975. To attain this goal, the Japan Atomic Research Institute, all nine utility systems, the five main atomic industrial manufacturing groups, and the recently established Japan Atomic Power Company have been studying nuclear power technology for the generation of electric energy, ship propulsion, and other applications.

Initially, the Japan Atomic Power Company intends to complete a British-type gas-cooled reactor in Tokai Village, 50 miles north of Tokyo, in 1963. Construction is expected to start during 1959.

Union of Soviet Socialist Republics. In August 1958, the writer had the opportunity to visit the USSR in a group from our nation's electric power industry. It may

be helpful to review Soviet nuclear progress in the framework of the present-day electric power facilities.

Soviet generating stations, although not incorporating turbine–generator units as large as some of ours, are modern and well designed. Because of the large area that must be served, high-voltage transmission lines (400 kv) are well developed and in service within the country. Also in operation is an experimental 200-kv d-c transmission line.

Until recently, the USSR has doubled electric energy generation every 5 years. Now they anticipate doubling it every 6 or 7 years. Their objective is to provide adequate electric power to meet the demands of their rapidly growing economy at the lowest possible cost. For the present and the immediate future they, like ourselves, realize that this must come from hydro and conventional thermal plants.

About 20% of the Soviet Union's approximately 48 million kw of generating capacity is derived from hydroelectric plants. We visited Kuibishev, the newest plant on the Volga and the largest hydroelectric plant in the world. It includes 20 generators, each with a capability of 115,000 kw. The engineers and directors we talked with indicated that in the future they will tend more toward thermal plants because of the great capital cost of a hydro installation and the extended time needed for construction.

Although the Soviets expect to install 60 million kw in the next 7 years, most of which will use conventional fuels, it is evident that they are making good progress in the nuclear field. Basically, their approach is like ours. They have no urgent need to produce electric energy by fission power because they, too, have extensive fossil-fuel resources. Therefore, they are studying various reactor concepts in an effort to determine the best and most economic types for future use.

Their over-all development program and present reactor installations were discussed at the second Geneva Conference in September 1958. They have a 5,000-kw pressurized water reactor plant that has been in operation since 1954, producing electricity, but primarily for research purposes. A 100,000-kw pressurized water reactor, the first unit of a 600,000-kw plant, is in operation in Siberia. It is reported that operations are under way to establish nuclear power facilities in Voronezh and Beloyarsk. Several more are contemplated in the long-range plan.

We understand that two prototypes are now under construction—a 50,000-electric-kw boiling water reactor and a 35,000-thermal-kw homogeneous heavy-water uranium oxide plant. A fast-breeder and a sodium-graphite facility are foreseen.

Like ourselves, the Soviets feel that the breeder reactor holds great promise of being commercially successful and, therefore, have a well-defined program for its development. They built and operated for a while a small research breeder, followed by a 5,000-kw installation that was operated and later discontinued to make way for a 50,000-kw plant now under construction. They plan, in turn, to design and build a 250,000-kw fast breeder power plant for industrial use in the future. All of these are designed for plutonium fuels, indicating their belief that the key to a successful nuclear power program is to be found in the use of plutonium and the breeding principle.

We received very fine co-operation during our visit. Our hosts were most willing to discuss many problems and activities of mutual interest. We learned many things from them and they, in turn, benefited from our experience. I feel strongly that if more meetings and free exchanges of information such as this were possible, the people of the world would become more closely united and that much nearer to a lasting peace.

SEEKING ORDER IN COMPLEXITY

WE BELIEVE that, in time, nuclear energy will have a profound effect upon the electric power industry. At some time, we will reach the point where the capital costs and operating expenses of nuclear power plants are such that the real cost of power so derived is competitive with present conventional plants. How then should we proceed so that nuclear power may assume a proper perspective in the economic order of events and become a sustaining force in our national and international economy?

The problem may be resolved into four areas of development:

1. Science, Technology, and Engineering
2. Economic, Capital, and Commercial
3. Legal, Liability, Government, and Political
4. Management, Educational, and Over-all Accomplishment

Science, Technology, and Engineering. Through the endeavors of scientists and engineers, we must learn how to build and operate economic nuclear reactors for the generation of electric energy and for other uses.

Many fail to realize the difficulties that lie between a technical concept and its practical realization. Considerable emphasis must be placed, at this time, upon all the painstaking developmental work that must be done. For example, up to 2 years may be required to determine by irradiation tests whether a proposed type of fuel assembly is acceptable.

Many of the problems are highly technical and difficult for even well-informed nontechnical people to appreciate. The task would be much easier for our scientists and engineers if their activities were more widely understood and thereby less affected by general impressions of over-optimism and over-pessimism.

Economic, Capital, and Commercial. The successful operation of many reactor concepts has been proved from the technical standpoint. Others, based upon design studies, appear highly promising. From a business standpoint, however, we would be delaying progress if we undertook an accelerated reactor construction program before units can be built at a cost as low or lower than available conventional units.

In addition to the heat generated by nuclear fission, there are numerous by-products that almost certainly can have commercial value, although it is still too early to say how much. Some authorities consider such potential revenues as important as the electric energy revenues that are anticipated. If true, this will be an important factor in reactor plant economics.

Continuing economic studies are necessary in the meanwhile to make sure that we do not become engaged in costly projects leading up blind alleys.

Legal, Liability, Governmental, and Political. With the development of reactor technology, we find ourselves confronted by a new array of legal problems. For example, the AEC has comprehensive rules and regulations under which those engaged in nuclear activities must operate. State and local regulation has also grown in complexity.

The revision of the Atomic Energy Act of 1954 relaxed somewhat the Federal monopoly and the degree of emphasis upon military application of nuclear technology. Security regulations were progressively relaxed but, nevertheless, a considerable degree of control was expressed in many new regulations. Today, the nuclear engineer must operate within the complex legal limitations imposed upon such activities. Such rules will affect the rate of development.

Inherent in the situation is also the old conflict between the proponents of Government ownership and those who believe that the strength and security of our democratic system depends, to a very large extent, upon the efficiency and freedom of competitive enterprise. The basic issue is often confused by the fact that the initial experimental and developmental work was done by Government for wartime application. In the welter of debate on this issue, one question is actually at the heart of the matter: Do we or do we not believe that competitive enterprise is essential to our way of life? Most of us in the United States are most certainly of that belief.

Another factor complicating the logical development of nuclear energy is the question of national prestige in the international field. This has preoccupied responsible people in many nations, not always without adverse effect upon their long-range interests in the nuclear field.

Management, Educational, and Over-all Accomplishment. Nuclear energy technology presents many new problems and requires a competent grasp of technical, economic, governmental, and legal data in reaching solutions. The financial aspects of supporting nuclear development require particular attention. Another serious management problem is the development of personnel for this new range of activity. It is important to co-ordinate progress along the four channels of development. In this way, we will make the best possible use of the men, money, and materials committed to this activity.

LOOKING TO THE FUTURE

So many factors will affect the future of nuclear power development that predictions are hazardous. Nevertheless, certain outlines appear highly probable.

The conventionally fired power plant has been developed to such a high level of efficiency by our industry that in developing competitive nuclear power our engineers are really competing against themselves. This, of course, is how it should be. Many conventional thermal plants will be built in the future. There is no reason to believe that nuclear energy will make conventional facilities obsolete during their economic lifetime.

There is no definite evidence that sets a term to the availability of conventional fuel for our power plants in the foreseeable future, although it is clear that, in time, significant depletion will occur. The growing demand for oil and natural gas for transportation and heating will increasingly compete against their use in power plants. Coal is a bulky fuel and transportation is costly. Our fossil fuels are also of growing importance in chemistry; some day they may even be considered too valuable to burn. Many factors make it clear that conventional fuel costs will trend upward and that, in the long run, high-energy civilization will find nuclear energy indispensable.

At the present time, there is an overabundance of coal in Western Europe, resulting from economic conditions and the greater use of oil and natural gas. This is probably a temporary condition and certainly does not change the fact that Western Europe's coal resources are indeed limited from a long-range view. The recent discovery of extremely large reserves of oil and natural gas beneath the sands of the Sahara may change the energy picture in Europe significantly in the years ahead. Many statements about nuclear power requirements abroad were predicated upon the possibility of immediate fuel shortages in the industrialized nations. In the leading countries of Europe, there is no longer the same sense of pressure. Even the USSR is apparently having some second thoughts on the necessity for all-out nuclear development to meet a fuel shortage in the immediate future. How much this change in attitude in Europe will affect nuclear programs remains to be seen, although there is evidence of a hesitancy in many places to commit large sums of money at this time.

For political reasons that are easily understood, other nations will not want to be dependent solely upon the United States for the supply of enriched uranium to fuel their nuclear power stations. Diffusion plants and the necessary supporting facilities are so costly that they cannot presently be justified on a power-only basis. It therefore appears that although some countries will find it expedient to build initial plants using U-235 enriched fuel, it is probable that—from the long-range standpoint—breeder reactors and possibly those using natural uranium enriched with plutonium will find acceptance both here and abroad.

There is evidence—Euratom, for example—indicating that the nuclear energy industry will develop along lines

of a high degree of interdependence both in the exchange of technology and in the construction and use of auxiliary facilities. This could be a strong force for the removal of international barriers to understanding.

The Technical Appraisal Task Force of the Edison Electric Institute recently concluded that there is a very good chance that the cost of nuclear power may become competitive in some parts of the United States in the next 10 or 15 years. The task force did not believe it possible at this time to identify the type of reactor most likely to prove successful and, therefore, recommended an aggressive research and development program encompassing a number of reactor concepts.

We need not try to identify the most promising power concepts in this article. The AEC, the Joint Committee on Atomic Energy, and many experts in the technical and industrial fields are studying this problem intensively. From the projects which have been completed and are in operation, and the work proceeding on projects described in the foregoing, we may be sure that several promising reactor types will emerge. Whether they will prove competitive with present conventional power plants is still debatable.

It is my feeling that the major cost problem lies in the fuel cycle, rather than in capital investment. We must develop a plutonium technology and a plutonium fuel cycle so that the atomic power industry will not be dependent upon gaseous diffusion plants for enriching materials. In line with this, we must develop breeder reactors so that all the potential heat in uranium can be utilized, rather than just a part of it.

We need better materials for fuel elements which will have much better resistance to fission damage. We also need less costly methods of fabricating fuel elements and less costly ways of reprocessing irradiated fuel elements. Good results are being attained in these directions, but there is still much to do.

Some think there is little urgency for the development of plutonium technology because the world has large uranium reserves. Most reactors, however, will use not more than 5% of the heat potentially available in natural uranium ore. Considering the long-range needs of the human race for abundant energy, it would be unthinkable for us or any nation to view with equanimity the discarding of the greater part by far of this precious resource. On the basis of present knowledge, this can be accomplished for the electric power industry only with the help of reactors of the breeder type used in conjunction with other kinds of reactors capable of using plutonium as a fuel.

Potentially greater than the fission process in effect upon civilization is the possibility of controlled nuclear fusion, which would use as a fuel the very abundant isotope of hydrogen known as deuterium. Given enough fusion power our industry would not need any other source, almost by definition—and there would be no problem of radioactive waste disposal. Nevertheless, even the brightest expectations for eventual success in harnessing the fusion process should not affect our practical judgment of the importance of fission technology and our desire to make the best possible use of fissionable and fertile materials. This is within our grasp, here and now, and we would be wise to develop it accordingly.

In defense of the current emphasis upon mills per kilowatt-hour as the prime measure of performance, it is worth remarking that our American economy is effective just because we are so concerned with cost. The urge to reduce unit cost—whether of a bushel of wheat, a ton of steel, or a kilowatt-hour of electricity—is the driving force that leads to better methods of production and distribution.

More has been accomplished in nuclear energy technology to date than most Americans realize, mainly because there is no easy way to measure highly technical accomplishment. At this point, it would be quite easy to ease the tension by doing something "big" that everyone could understand, such as building at Government expense a brace of large nuclear power plants along the lines of fairly well-established designs.

Unfortunately, this would commit for some time to come a large amount of scientific and engineering talent and a lot of capital. There would be no built-in guarantee that we were building the best possible kind of reactor, because this is still at issue in the most competent circles. As a nation, we might make a lucky guess, in which case all would be well. More likely, we would not.

In other words, although everyone would like to find a short cut to the most economic and effective form of nuclear power, there is no royal road that we can follow. We will best serve national interest if we proceed step by step, searching as we go, with the openness of mind that befits a scientific age, fully aware that we are responsible for the optimum development of one of the greatest discoveries in the history of the human race.

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Progress in Power Apparatus

A. C. MONTEITH

FELLOW AIEE

IN ANY DISCUSSION of the progress in power apparatus, an impressive fact emerges: an increasing number of challenges is being presented to the industry to conceive systems and provide apparatus that will continue to give more power to the American worker, at lower and lower cost. This is the strength of American industry and the free enterprise system, to which the electrical industry has made a major contribution. The fact that the American worker now has more power available to him to do the dull or routine tasks is building his stature with respect to workers in similar jobs in other countries. The electrical industry has done much to provide this high standard of living.

The rate of progress in electric equipment depends, to a large degree, on the rate that new knowledge can be acquired and put to work. For example, during the past 25 years, the temperature of steam admitted to turbines has risen from 825 to 1,200 F. While many factors enter into this, it is safe to say that this increase could not have been made without new materials that have resulted from research and development. In the same time span, the maximum rating of 3,600-rpm single electric generators has risen from 25,000 kva to a present high of 384,000 kva. Many factors are involved, including improved rotor forgings, better insulation, and the application of an entirely new concept of cooling. All of these improvements have their base in research and development. The same condition holds for power transformers and switchgear, where new knowledge has been used to equal advantage.

A steady flow of new information, new materials, and new techniques has given the design engineer the means to fulfill the needs of electric utilities. The engineer has done his job well, as can be judged by considering the four major areas of heavy power apparatus—turbines, generators, transformers, and switchgear.

STEAM TURBINES

THE METALLURGIST must be given a full share of credit for today's highly efficient power plants; steam turbines operating in these plants make possible a station heat rate approaching 8,000 Btu per kwhr (Fig. 1). His ability to crash metallurgical roadblocks has been one of the outstanding scientific contributions of the past quarter century.

The root of this ability is a continuing research program that has expanded the metallurgist's knowledge of the atomic structure of matter. As a result, he can now give the turbine design engineer better metals. For this reason, the output of a 25-year-old generating station can now be doubled without increasing the building size or reinforcing the floors. In comparison with its 25-year-old counterpart, today's steam turbine needs but half the floor space per 1,000 kw of capacity and weighs but one third as much per kw.

This does not mean that the turbine design engineer has not made significant contributions. To mention a few, he has such accomplishments as the regenerative feedwater heating cycle, the reheat cycle, the accelerometer governor, supervisory instruments, and multiple exhaust flow and longer exhaust blading for increased kilowatt rating. But the fact remains, the design engineer is hard put to develop a better turbine

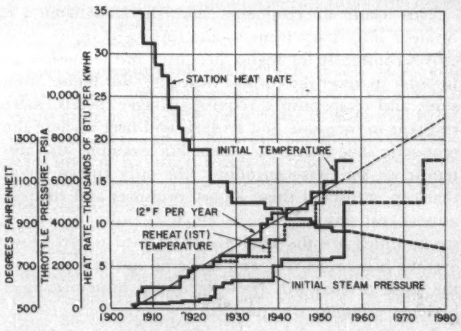

Fig. 1. Trends in initial steam pressure, initial and first reheat temperatures, and station heat rate.

with existing materials. So, in the final analysis, the advances in turbine design are the result of parallel programs: continuing research, which has expanded greatly the metallurgist's understanding of atomic structure of matter; and a continuing development program, which has added to the design engineer's knowledge of applied mechanics.

Thermal cycle development during the past 15 years has necessitated radical changes in design concepts to meet the ever-increasing severity of operating conditions and the growing demands for greater reliability and operating flexibility. Pressure increases have made necessary heavier-walled steam piping, steam chests, and turbine casings, while temperature increases have

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reduced permissible stress levels. Alloyed metals have provided some relief to stress levels but, of necessity, walls have been made thicker than pressure increases alone require. As a result, there is a greater mass of metal to heat and cool, and with the higher temperatures there is a greater temperature gradient as well as more severe transient thermal stresses. The philosophy of design for high-pressure high-temperature parts solves this problem by limiting physical size, maintaining simple shapes, and providing freedom of expansion.

Metals Pace Progress. During the past quarter century, the continual improvement in metals has made possible an eightfold increase in steam pressure, from 650 to 5,000 psig (pounds per square inch, gauge) and a 50% rise in steam temperatures, from 825 to 1,200 F (Fig. 1). As a result, about 1½ times as many kilowatt-hours are generated from the same amount of fuel. While this is a measure of progress that should be pointed to with pride, the stark facts are that a point has now been reached where the laws of economics and thermodynamics meet head on. Because progress is an irresistible force, further increases in pressure and temperature can be expected, but the rate of increase will be determined by the metallurgists' ability to develop metals that will make this economical.

This clash of economics and thermodynamics is brought into sharp focus by the turbine designer, who strives constantly for higher pressures and temperatures in order to lower the turbine heat rate. But higher pressures and temperatures require stronger metals, more resistant to corrosion and erosion, and here's where the economic shoe begins to pinch. For example, the austenitic, or stainless-steel alloys (the only known metal that can withstand these higher pressures and temperatures) cost several times as much as ordinary ferritic steels, which are the kind generally used today. However, as fuel prices rise—and make no mistake about it, the price of coal will rise—the use of austenitic steel becomes economically justified.

This reasoning led to the decision to use austenitic steel in the turbine being built for the Eddystone plant of the Philadelphia Electric Company. This turbine will take steam at 5,000 psig, 1,200 F; will produce a station heat rate that will approach 8,000 Btu per kwhr; will carry a 325-mw load; will occupy less than 10 square feet of station floor space per 1,000 kw; and will weigh less than 4 pounds per kw.

Such a turbine represents a gargantuan stride from the low-pressure low-temperature turbines of the early 1930's. These turbines took steam at 650 psig, 825 F; produced a station heat rate of 13,000-plus Btu per kwhr; occupied more than 20 square feet of station floor space per 1,000 kw; and weighed 16 pounds per kw. These are the important units of measure of progress for the past quarter century. How they came into being is one of the great technological achievements of that period.

Contributors to Progress. Perhaps the close working relationship between manufacturer and the electric utility may be listed as the foremost contributing factor to progress. This relationship has accelerated development because the electric utility has been willing to accept new design concepts. These concepts have produced, in addition to better design configurations, improvements in the arrangement of extraction heating, and single and double reheat.

Unquestionably, next on the list of achievements is the better metals that have come from the research and development laboratories of the manufacturers. Directly related to such developments are the continuing educational programs carried on co-operatively by the manufacturer and universities, through which scientists and engineers have enlarged their knowledge of thermodynamics, fluid mechanics, physics, metallurgy; and chemistry.

As a result, among the many steam turbines now building or on order are those that will operate at new combinations of pressure, temperature, and capacity: pressures of 2,400, 3,500, 4,500, and 5,000 psig; temperatures of 1,050, 1,100, 1,150, and 1,200 F; and capacities of 300, 325, 425, and 500 mw. The amount of influence these steam conditions will have on future design is problematical, and will not be known until operating experience has been gained. But research and development programs and basic design studies cannot wait that long if progress is to be orderly.

Technological Considerations. The relationship between pressure and temperature, and between pressure and size, is determined by two practical considerations: materials and exhaust pressure. Pressures in excess of 5,000 psig with temperatures in excess of 1,200 F mean materials problems, as do reheat temperatures in excess of 1,050 F. High pressures for smaller rated turbines (50 to 60 mw) result in relatively poor turbine efficiency and consequently thermal gains too low to justify the increased cost. Low pressure for larger rated turbines (500 to 600 mw) result in such high volumetric inlet flow that throttle valves, steam chests, steam inlet piping from steam chest to turbine, and nozzle chambers become prohibitively large in size. In addition, the control stage requires such excessively long rotating blades that it would be difficult, if not impossible, to build.

Pressures above critical, and very large volumetric flows at subcritical pressures, impose design limitations when partial admission of steam is used to provide good part load performance because of the bending forces on the high-pressure rotor. One solution to this problem is the monotube, or once-through, steam boiler that combines variable pressure with partial admission at reduced load. All supercritical pressure turbines are now operated with 100% admission in the control stage with the control valves being throttled for reduction in load. Experience with the supercritical steam boiler will determine feasibility of variable pressure operation.

Steam pressure and, to a lesser degree, turbine rating determine the number of stages of regenerative feed-

Fig. 2. Forging of 44-inch blade for low-pressure element of 5,000-psig superpressure turbine.

water heating. For example, a 1,450-psig 50-mw turbine might have five stages of feed-water heating whereas a 5,000-psig 500-mw turbine might have nine stages.

The range of pressures, temperatures, and sizes existing and foreseeable requires a large number of turbine combinations. These combinations vary from the single-cylinder single-flow, relatively low-pressure 3,600-rpm nonreheat single-shaft for the 10- to 40-mw turbine-generators, to the 4-cylinder quadruple-flow, to the octuple-flow superpressure 3,600-rpm double-reheat cross-compound for the 400- to 800-mw unit. Of interest are the 1,800-rpm nonreheat single-shaft turbines in ratings from 75 to 350 mw for nuclear plants. These differ from conventional turbines in that their design provides for low-pressure and low-temperature steam conditions.

Advances in metallurgy and mechanical design have made possible longer rotating blades, and these longer blades increase turbine output for a given configuration. For example, 28-inch-long blades in the last row of each stage of a quadruple-exhaust single-shaft 3,600-rpm turbine generator will permit the unit to deliver 25% more power than the 25-inch blade—400 mw instead of 325 mw. Cross-compounded, two such turbines will result in an 800-mw unit. But this increase in blade length presents an exhaust casing problem, among others. If, for example, the last row blade length in a 3,600-rpm element is increased from 25 to 28 inches, a 25% increase in exhaust hood flowing space must be provided.

Some of the largest turbine blades ever designed—44-inch exhaust blades for the 5,000-pound superpressure turbine—are shown in Fig. 2.

Rotor Forgings. Hydrogen-free rotor forgings in the lengths and diameters needed for the largest turbines are the latest metallurgical contribution to progress. All forgings are inspected in two ways: by optical instruments that require a center bore hole, and by ultrasonic instruments that rely on transmitted sound waves and their reflection. In addition to fabrication procedures, manufacture includes tempering in a seasoning and balancing box, and, finally, subjecting to a rotating test at 20% above normal speed, or 4,320 rpm for a 3,600-rpm rotor.

Steam control-valve development has kept pace with that of other turbine elements. As a result, two stop-throttle valves in parallel are used on the higher-rated turbines. Either valve can be closed completely to be sure it operates through the full stroke with but a 15% reduction in maximum output. Stop valves are designed for use as throttling valves when starting the turbine, and all control valves are fully open. An important by-product of this paralleling of stop valves is that this assures a valve body and bonnet size that can be forged.

Steam Cooling and Turbine Types. Steam cooling of high-temperature parts has been extended to extra-high-pressure and superpressure turbines. The control stage flow is reversed from the normal arrangement so that the steam from the control stage flows between the nozzle chambers to the lower pressure stage. Since the temperature drops from 75 to 100 F in the control stage, the inner casing is maintained at a lower temperature than if it were subjected to radiation from the nozzle chamber without cooling from the lower-temperature steam.

Mass-flow steam cooling can be used to reduce the mean temperature of the turbine casing walls and, consequently, the thickness. The thermal stresses that result must be less than the increase in allowable stress; otherwise there can be no reduction in wall thickness. This form of cooling is especially beneficial in reducing transient thermal stresses incident to thermal cycling that result from load changes, overnight or week-end shutdowns, and cold starts.

Mass-flow cooling is a feature of the advanced design embodied in the tandem-compound double-flow 3,600-rpm reheat turbines that are available in capacities from 50 to 175 mw. These turbines are designed to cover a range of steam inlet conditions from 1,450 psig, 1,000 F to 2,400 psig, 1,050 F with single reheat to 1,000 F, respectively.

The high-pressure/intermediate-pressure element embodies, in addition to mass cooling, rotor cooling and thrust balance under all conditions of steam flow. Steam for mass-flow cooling is taken from an extraction point following the return of the reheated steam to the turbine. Cooling results from the temperature drop in the steam of 150 to 200 F.

Steam cooling of that portion of the intermediate-pressure rotor subjected to reheat steam (at 1,000 F) is accomplished by leakage steam through the center gland at the exhaust end of the high-pressure turbine element. Lower-temperature steam from the first part of the intermediate-pressure turbine element flows across the high-pressure casing and steam-inlet features and cools them. The steam flow continues to the remaining blading of the intermediate-pressure element and carries with it all leakage steam.

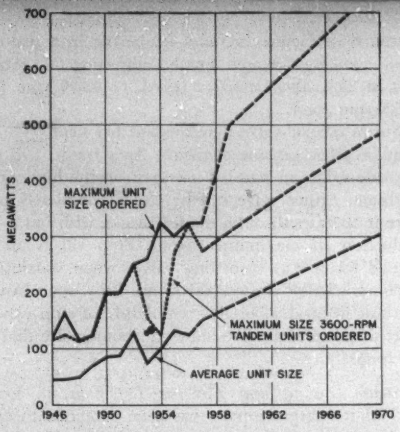

Fig. 3. Maximum and average turbine unit sizes have more than doubled since 1946. Also shown is trend of maximum size of 3,600-rpm tandem units.

The tandem-compound triple-flow 3,600-rpm reheat turbines extend the ratings of this type from 125 to 250 mw, depending on the steam inlet conditions and exhaust pressure. This turbine uses the 25-inch-long blade in the last row of each stage of exhaust. Inlet steam conditions range from 1,800 psig, 1,000 F to 2,400 psig, 1,050 F with single reheat to 1,000 F and 1,050 F, respectively.

A special modification of this type is a 215-mw unit designed for steam conditions of 3,500 psig, 1,100 F with 1,050-degree reheat. The modification replaces the conventional high-pressure element and a portion of the intermediate-pressure element with a superpressure element and a very-high-pressure/high-pressure element. An intermediate-pressure/low-pressure element in a single case and a double-flow low-pressure element complete the turbine.

A notable feature of this turbine design is the use of ferritic steels for the superpressure element where steam enters at 1,100 F—50 degrees higher than any previously designed turbine made of ferritic materials. The steam plant in which this turbine operates will develop about 4½% greater thermal efficiency than the best plant now in operation.

The most advanced turbine—the cross-compound double-flow 3,600/1,800-rpm superpressure double-reheat turbine—is designed for steam conditions of 5,000 psig, 1,200 F. These initial steam conditions, plus double reheat to 1,050 F and nine stages of regenerative feed-water heating, make the steam plant in which this 325-mw unit operates the most efficient yet built.

The outstanding design feature of this turbine is the superpressure element. The steam valves, inlet features, nozzle chambers, and inner casing are of austenitic steel. The turbine rotor will be of Westinghouse Discaloy steel.

The design engineer has used the 25-inch-long blades in the last row of each exhaust of the tandem-compound quadruple-flow 3,600-rpm reheat turbines to produce a unit up to 325-mw. Steam conditions for this design call for 2,000 psig, 1,000 F to 2,400 psig, 1,050 F with single reheat to 1,000 F. Ferritic materials can be used for the upper limits of steam conditions.

The 3,600/3,600-rpm cross-compound turbine generator with the low-pressure ends evenly divided offers many advantages, one of which is duplicate generators. As demand for larger ratings exceeds the capacity of 3,600-rpm single-shaft units, their use will increase. A unique advantage of the 3,600/3,600-rpm unit is that of being able to use two half-capacity boiler-feed pumps, one driven from each of the main generator shafts through a mechanical disconnecting coupling, a hydraulic coupling, and a step-up gear. The economics of boiler-feed pumps, main turbine shaft driven, motor driven, and separate turbine driven, depend on local conditions and operating practices.

Development and the Future. The steady growth in the ratings of turbine units is indicated in Figs. 3 and 4. The design and construction of larger turbines rests on a continuing research and development program. Advance development studies of exhaust-end blading have resulted in over-all turbine improvements of more than 1%. Studies of exhaust hoods have also been made. These indicate that design changes in the hood could add another 2% in over-all improvement of turbine performance.

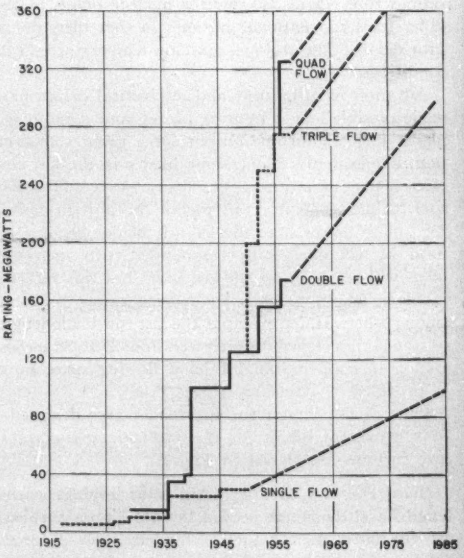

Fig. 4. Actual and predicted growth of 3,600-rpm tandem machines according to flow type.

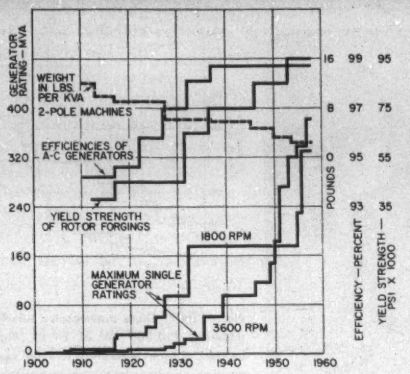

Fig. 5. Summary of a-c turbine–generator progress during the past few decades.

Another advanced study has been made of combining the gas turbine with a steam plant to increase thermal efficiency. This combination will be practical when the gas turbine can take the products of combustion from a coal-fired boiler. One problem now being worked on is better separation of fly ash. The answer may come from metallurgical research efforts, or it may be found in engineering techniques that permit separation of the fly ash from the products of combustion, the gas that must drive the turbine. At any rate, the combined gas-turbine cycle, using coal as a fuel, is another possibility that must be studied if more efficient prime movers are to be developed for the future.

GENERATORS

THE ABILITY to build ever-larger generators during the past 25 years has depended largely on remarkable improvements in cooling methods, insulation, and rotor forgings.

Generator Cooling. The steady improvement in cooling has been enormously important in enabling designers to meet the continually rising demand in kilowatt output indicated in Fig. 5. From 1920 to 1935, 1,800 rpm was the predominant speed, and generators up to 183,000 kva were built. Starting in 1935, 1,800 rpm gave way to 3,600 rpm, and hydrogen replaced air as the cooling medium.

Early hydrogen-cooled machines were operated with a pressure of 0.5 psig, just enough to insure that any leakage would be outward. It was known, however, that a denser gas would be more effective as a coolant. Hydrogen pressure was gradually increased to 30 psig, which resulted in a gain in output of 25% over the 0.5-psig rating. With pressures above 30 psig, any gain in rating of conventionally cooled machines would become very small and would not justify the higher windage losses and the increased cost of the gastight housing.

Despite the improvement brought about by hydrogen, by 1950 it was anticipated that mechanical requirements would limit increases in generator size. Rotors were rapidly approaching the point where the strength and size of the forging available within the foreseeable future would prevent any additional increase in diameter. Further restrictions were imposed by the permissible shipping dimensions, which determined the maximum size of frame housings that could be constructed as integral units. Also, in conventional units, all the coil losses were dissipated through the electric insulation so that inherently an appreciable thermal gradient occurred at this point. With any of the cooling methods that are confined to the thermal circuit outside the insulated coil, the coolant exercises only a secondary role in reducing the temperature rise of the electric conductor.

To remove the limitation, a more effective cooling method was necessary, one that would allow the thermal barrier of the electric insulation to be eliminated. This objective was realized by inner-cooling. Here the active conductors are made hollow and the gas coolant blown through them at high velocity. Thus, the cooling agent is in direct contact with the source of heat, resulting in more efficient heat removal than with any previous method.

The stator presented a different problem. Stator conductors must be made of many fine strands to limit eddy-current loss. Thus, ducts of thin-walled high-resistance metal are imbedded within the conductor strands to carry the cooling gas from one end to the other. These tubes are electrically insulated from the copper by very thin insulation. Both high static pressure and high fan pressure are desirable, and this led to further development of better shaft seals and axial-flow fans.

This technique of inner-cooling made it possible to get almost twice the electrical output from a machine of given size. Turbine–generator rotor diameters have been reduced 15%, with an attendant rotor weight reduction of 45 to 50%. For example, the rotor diameter of a 350,000-kva 3,600-rpm 45-psig inner-cooled turbine generator is the same as was previously used for a conventional generator of the same speed, rated at 66,600 kva at 30 psig gas pressure.

The first inner-cooled machine was placed in service on the Niagara–Mohawk Power Company system a little more than 5 years ago. This machine has a nominal rating of 100,000 kva at 30 psig hydrogen pressure, and a maximum rating of 125,000 kva at 45 psig. Since that time, inner-cooled units totaling more than 17 million kva have been built or are on order. One large machine, a 250,000-kw generator, is shown in Fig. 6.

Rotor Forgings. Ten years ago, Westinghouse Electric Corporation initiated a major development program to improve the quality of rotor forgings. A forging committee was formed with design and metallurgical representatives from all over the company. They were assigned the responsibility of investigating all

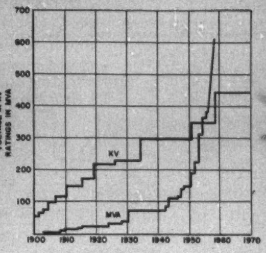

Fig. 6. (left). These inner-cooled windings generate 250,000 kw at 24 kv. Fig. 7 (center). Silicon semiconductors for use in exciting circuit to eliminate commutators, collector rings, and brushes. Fig. 8 (above). Maximum voltage and power ratings for transformers have been rising steadily.

the factors involved in improving rotor forgings, including composition of metals, procedures, and methods of manufacture. To translate the results of research effort into improvements in the quality of rotor forgings, co-operative studies have been conducted with steel suppliers. This program has resulted in marked improvements in the manufacturing processes, and development of quality control methods, such as ultrasonic inspection, which insure that only forgings of the highest quality are used.

As a result of the importance attached to low hydrogen content of forgings, principal suppliers have found that with changes in melting practice, and more attention devoted to the control of impurities, cleaner steel can be produced with fewer inclusions and with more uniform properties. By exercising more exacting controls, the most troublesome impurities, sulfur and phosphorus, have been materially reduced.

All of the suppliers are now equipped to make most of their forgings from basic electrically melted steel. They are all increasing rapidly their electric-furnace capacity to take care of the increased demand for this type of forging.

In addition to better melting techniques, all the suppliers have, or are installing, vacuum-pouring facilities. The equipment in each of these installations is adequate to cast ingots of a size sufficient to make the largest rotor forgings required.

Results obtained from the vacuum-pouring technique and the use of electric melting are excellent. This process has resulted in improved ductility and quality throughout the forging by the reduction of hydrogen content and impurities. Analysis shows that the hydrogen content can be held well below that necessary to assure high ductility and freedom from significant internal stresses in deep-seated parts of large forgings.

Experimental forgings have been made with new compositions to give relatively low transition temperatures. When new metal analyses are used, however, care must be exercised to use a composition that will not reduce the magnetic permeability and, thus, make the material unsuitable for generator rotors. Continued progress in this field should soon make it possible to obtain forgings having all the desired electrical and mechanical properties.

Cube-Oriented Steel. Over the years, improvements in magnetic steels consistently have raised the efficiency of electric apparatus. This has lowered losses, conserved power, and reduced the total electric bill of the Nation.

This project continues and involves development of basic electrical sheet steels, which will have lower losses and good magnetic properties in all directions. The newest alloy to meet these requirements is a cube-oriented silicon iron called Cubex. This alloy has obvious advantages when applied to generator stator core assemblies. In these assemblies, maximum use is made of single-oriented material by punching the teeth in one direction, the wide curved section in another direction, and then welding the two together. A single punching from the new cube-oriented material could satisfy this 2-direction orientation requirement.

Experimental work has shown that cube-oriented iron alloys can be made. The work required now will be to obtain a deeper understanding of the factors involved in the preparation of the material for widespread commercial use.

Insulation. The perfect insulator, like the perfect conductor, will always remain a goal, not an accomplishment. Nevertheless, progress toward it is continual, sometimes by small increments, occasionally by giant steps. The year 1950 marked one of the major steps—a vastly superior material for the stator coils of high-voltage generators, christened Thermalastic insulation. This insulation consists essentially of mica flakes

bonded with a strong resilient synthetic resin. The insulation has sufficient resiliency to contract as well as expand with the coil, plus physical strength to withstand the expansion forces.

Since 1950, more than 500 large generators representing 30 million kw have been built using Thermalastic insulation. This involved the manufacture of more than 50,000 individual coils.

The success of Thermalastic insulation stimulated further efforts by insulation research and development engineers in two major directions.

First, improved resins for both tape bonds and impregnating resins have been developed within the basic Thermalastic concept. These improved resins both contain epoxy-like molecular linkages, which produce better physical strength, greater extensibility, improved adhesion, and with even more resistance to thermal degradation. These new resins have been used in stator-coil insulation for all hydrogen-cooled turbine–generator stator windings made since the third quarter of 1955. Comprehensive tests indicated that the improved resins have improvements of at least 20 C in temperature stability for equal life.

The second improvement has been the elimination of the cellulose backing for mica tape. This is not a simple problem because of the need to maintain a high percentage of mica in the finished insulation wall. Until very recently, thin glass cloths, with a thickness of 1 mil, have not been available commercially on a production basis. The cloth was first imported from France for experimental work in 1952, and limited scale production began in 1953. Subsequently, United States suppliers have developed a commercial product and are now supplying this thin glass fabric. The end result has been insulation systems with even greater thermal endurance.

Exciters. The trend to larger and larger excitation requirements for turbine-driven generators has resulted in major design changes on exciters in the last 10 years. Today, exciters are built with capacities in excess of 1,500 kw and even higher ratings will be needed soon.

The exciter is a small supplementary generator that produces the magnetic field in large generators. It generally requires the use of current-collecting parts such as commutators, collector rings, and brushes, parts that wear and require removal and replacement. Through the use of silicon semiconductors, these moving parts can be eliminated. Silicon rectifiers, such as that shown in Fig. 7, make possible the substitution of an a-c generator for a conventional d-c exciter, thereby eliminating the brushes. Silicon rectifiers have been available for some time, but only very recent developments have made them practical for central-station excitation systems.

With the use of semiconductors, the excitation system of tomorrow will have no current-collecting parts —no brushes, no collector rings, no commutator. Small experimental units of this type have already been built. Larger ones can be built now. All this will eventually mean the elimination of brush maintenance and provide greater reliability.

The end result of these developments will be higher-quality materials for the generators of the future. Hydrogen was discussed as the cooling medium in generators, but oil, water, other gases, as well as vaporization methods, also have been studied. While all of these have some merit, the hydrogen inner-cooled machine has not reached the limits of its capabilities. When other cooling methods are developed to the point where they will deliver the same degree of "on the line" reliability, they will be built.

Five years ago, a big breakthrough was made with inner-cooling. This new cooling system has enabled designers to keep well ahead of the needs of the electric utility industry for larger, more efficient turbine–generators. Today, the average size of these inner-cooled generators is over 200,000 kva. A 320,000-kva single-shaft 3,600-rpm unit has been in service for more than 2 years. In fact, a larger unit of 384,000 kva is being built for Arkansas Power and Light Company. For tomorrow's systems, design work is progressing on 448,000-, 480,000-, and 512,000-kva single-shaft generators. Therefore, future systems can be planned with assurance that whatever is needed in turbine–generators will be made available.

POWER TRANSFORMERS

THE TREND that exists in all fields of heavy power apparatus—namely, rapidly increasing electrical ratings —is especially evident in power transformers, as indicated in Fig 8. A curve of maximum transformer ratings shows that the increase for the first 30 years of this century was steady, but not particularly startling. Then, in the 1930's, came a real jump to about 70,000 kva, after which ratings again remained relatively static until the mid-1940's. Since then, ratings have soared. The maximum of about 70,000 kva in 1940 more than doubled, to 150,000 kva, by 1950. Since 1950, the ratings have risen more than 2½ times, to a 380,000-kva unit installed in 1958.

Voltages, while not rising in the same manner, have also jumped, from the maximum of 287 kv in the 1930's to 345 kv at present. As a matter of fact, 117 units of the 345-kv size have already been built or are on order by the industry, and higher voltages are in prospect.

Equally striking is the weight reduction that has occurred since the 1930's. A 70,000-kva transformer built about 1930 weighed 500,000 pounds; the same rating today weighs but 207,000 pounds. Or, to compare weight in different terms, a 30,000-kva transformer built in the early 1930's weighed 590,000 pounds; this transformer was built to have a future air-blast rating of 45,000 kva. By 1953, this weight had still not been surpassed; in fact a 150,000-kva unit built then weighed only 500,000 pounds. The same trend continues; a 360,000-kva generator transformer completed in 1958 has an installed weight of only 460,000 pounds.

Obviously this trend of increased ratings and de-

Fig. 9 (left). First inner-cooled transformer, in which oil is circulated between the strands of parallel conductors at the same potential. Fig. 10 (above). Shipment of larger transformers has been made possible by the Schnabel car. Transformer is suspended between the two halves of the car.

creased weight could not have occurred without some major design improvements.

Core Steel. A major contributor to the designer's ability to increase ratings while decreasing weight has been Hipersil, a cold-rolled grain-oriented steel. If this steel could be used to its full capabilities, core weight could be reduced to one third that of designs using hot-rolled steel. Noise and a few other technical problems have thus far prevented maximum use of this material but even so it has contributed in a major way to lower weight per kva.

Co-ordinated Design. A second contributor to this progress has been the co-ordinated design of core, coil, and case that results in light weight, small size, and lower cost. Such co-ordination permits the use of forced-oil cooling, which allows a given self-cooled kva rating to be uprated 66%. Forced-oil cooling lends itself to the shell-form form-fit design. This construction is suitable for either self-cooling or any variation of oil cooling.

Impulse Testing. The third major contributor to progress has been large-volume impulse testing. Although on the surface impulse testing may appear to be only a way for a manufacturer to check his product, the procedure actually has had even more valuable effects. By assuring quality, these tests have fostered the application of lower insulation levels to systems designed and protected for such applications. The assurance of reliability plus the contributions of design improvements have also led to extensive use of one large 3-phase transformer in place of three, or sometimes four, single-phase units.

Other Major Improvements. While the three factors just mentioned have been the major items of transformer progress, they are supported by many other improvements. Inasmuch as equipment design must be based on needs of electric utilities, perhaps it is not surprising that the last decade, particularly the past 2- or 3-year period, has produced more than its share of new developments. Like the increase in maximum ratings, development has been accelerating.

1. Inner-Cooling. Until recently, transformers used a combination of oil ducts and cellulose material for insulation. Oil ducts on either side of the transformer coil allowed flow for cooling purposes. In this type of design, the dielectric strength of oil is the limiting factor, because actually the cellulose is used mainly as a spacer to maintain the oil duct . Because oil has a much lower dielectric strength than the cellulose, full use is not made of the available materials. With a new design, called inner-cooling, the oil ducts are placed *between* the parallel wound conductors of each coil. The coils are thus cooled from the inside. This construction takes full advantage of the higher dielectric strength of the cellulose material used on the outside of the coil, and still provides adequate cooling.

Inner-cooled construction allows lower impedances and improved performance, with more kva in the same space. For the same rating, space and weight can be reduced up to 15%. The first inner-cooled unit is shown in Fig. 9.

2. Insuldur Insulation System. A limiting factor in the life of oil-filled transformers has been the deterioration of insulating papers, which gradually lose their strength and become brittle. The addition of a new thermal stabilizer has made a significant change in the

life of paper insulation. The most important factor about this improvement is that power transformers with this new insulation system can carry more overload than conventional transformers. Where overloading is economically justified, power transformers can operate at 10% higher overloads without additional loss of life.

3. Transportation. One of the factors that dictates the maximum physical size of power transformers is the ability to ship the unit to its site. Although transformer designers must make a major contribution by keeping unit size down, better methods of shipment also have played an important role. The drop-center railroad car was a contribution to the solution of this problem. More recently, the center of the car has been eliminated completely. The transformer rests between two similar end sections, suspended between two trusses. A 90-foot Schnabel car (Fig. 10) can negotiate the same curves as a standard boxcar, and far sharper curves than the drop-center car. The transformer can be supported only 4 to 6 inches from the rails, thus making it possible for transformer designers to work with an additional 2 feet of height.

4. Sound Levels. Transformer noise has been one of the most difficult problems for designers. This is because sound level is a function of flux density; i.e., the lower the density, the quieter the transformer. Transformer requirements, however, have been going in the opposite direction, toward smaller units, and therefore higher flux density. A great deal of research has been devoted to sound levels (Fig. 11). As a result, they have been reduced, despite the higher flux density, at a rate of about 2 db per 7 years. An even greater rate of reduction may come about in the future because of present work on transformer iron, the heart of the problem..

5. Standardization. A noticeable trend toward standardization is taking place in the electric utility industry. The benefits of standardization are obvious, both from the standpoint of the manufacturer and the electric utility. One example has been the standardization of bushings, which has now been extended to include all bushings from 23 through 196 kv.

One of the more interesting engineering aspects of standardization is that it makes possible the use of digital computers to make designs, thus freeing engineering time for more creative effort on other problems. Standardized designs can be produced on digital computers at the rate of one every 4 minutes, and the results assure optimum designs.

6. New Methods of Cooling. Oil and air long have been the major cooling medium for power transformers. Recently they have been joined by a new method known as vapor cooling. Both a network transformer (Fig. 12) and a power transformer are now in service using a mixture of fluorocarbon vapor and sulfur hexafluoride gas for insulation and cooling.

In this type of transformer, the vaporizable liquid is pumped from a sump at the bottom of the tank and flowed over the coils. Here it absorbs heat, evaporates, then condenses on the tank and cooler surfaces and returns to the bottom of the tank as a liquid. The cycle then repeats.

A 7,500-kva vapor-cooled unit now in service requires no fan cooling up to its rated load, and will carry 10,000 kva with external fan coolers. The unit is about the same size as a conventional oil-immersed transformer.

The big advantage of the vapor-cooled transformer is safety. The vapor-gas mixture is nonflammable and nontoxic, and thus is ideally suited to residential districts or downtown areas.

The Future. What the future holds for power transformers depends largely on the needs of electric utilities, as is the case with every piece of major power apparatus. Higher voltages seem to offer no insurmountable problems; a transformer of 600 kv or more can be built when needed.

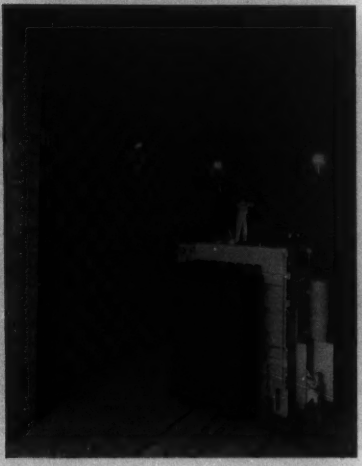

Fig. 11 (*left*). Sound laboratories such as this have been used for a constant attack on noise, as well as for other tests. Fig. 12 (*right*). First vapor-cooled transformer went into service in 1957. The 500-kva network unit is shown being installed.

Engineers in every decade have looked at shipping limitations and felt that the ability to move a transformer from a manufacturing plant to its utility destination would soon be *the* limiting factor. Ultimately, this may come to pass. But a review of the past 25 years indicates that every time this limitation seemed about to take effect, designers were able to pack more kva into the same package, and thus avert the problem. With continuing research and development, this limitation may not arise until some time in the distant future.

SWITCHGEAR

THE ABILITY TO GENERATE large amounts of electric power, and to transform this power efficiently to high voltages would be largely useless unless the system could be afforded adequate protection. Fortunately, designers of high-voltage high-power circuit-interruption devices have been able to keep up with and frequently ahead of the demands of power systems.

Many people, especially those outside the electric utility industry, may underestimate the effect that growth in the use of electric power has on apparatus design. If you consider almost any major piece of utility apparatus, the maximum ratings have risen faster than over-all power consumption. In large high-voltage switchgear, for example, while power consumption was growing by a factor of a little over six times in the 20-year period starting in 1935, the maximum interrupting capacity of circuit breakers rose by a factor of 10. This has involved far more than just scaling up the 1935 design. Research and development to find better designs, better components, and better materials were essential.

During the past 25 years, circuit breaker designs have been required to meet many new and more exacting requirements. Among the more important of these have been the greatly increased interrupting requirements and the need for faster interrupting and reclosing times.

One of the most significant steps in switchgear development occurred in 1934, when the Bureau of Power and Light of the City of Los Angeles decided to build a 287-kv transmission line from Hoover Dam to Los Angeles, Calif. The development of the circuit breakers for this application led to new standards for circuit-interruption devices. In the first place, this application required the largest interrupting capacity of any breakers built up to that time, 2.5 million kva at 287 kv. Because of the stability requirements and the importance of the service, an unprecedented interrupting time of 3 cycles was required.

The significance of this lies in the fact that until about 1929, high-voltage breakers had interrupting times as long as 16 to 20 cycles at 230 kv, and generally required maintenance after two operations. The introduction of the De-ion grid in 1929 suggested that faster switching could be provided with more operations between maintenance. Tests showed that interrupting times at existing voltages could be lowered significantly but the 287-kv line application was the most striking example of what could be accomplished.

Three-cycle interruption takes about the same time that a freely falling body will move $\frac{3}{8}$ inch, and in a circuit breaker this time covers tripping action, movement of mechanical parts, and arc interruption. To secure this fast action, a group of 10 De-ion grids was modified to obtain approximately uniform voltage distribution among the interrupters, thus forcing each unit to perform its share of the total interrupting duty. This method of using multiple interrupters, which were first proved practical in this development, is now the basis of most high-voltage designs in the United States.

The Hoover Dam breakers might be considered the beginning of a new era in circuit interruption, but equally significant developments were to follow. Perhaps the most striking example of progress in circuit breakers is the phenomenal growth in interrupting capacity. By modification of the original design, the interrupting capacity of the Hoover Dam breakers was increased to 3.5 million kva at 287 kv in 1941. In 1945, the American Gas and Electric Company required 3.5 million kva at 138 kv; the same utility required 6 million kva at 138 kv in 1949. The Aluminum Company of America required 5 million kva at 161 kv in 1949. The Grand Coulee Dam required 10 million kva at 230 kv in 1947. The latter case proved how well circuit-breaker designers had planned. Several older 3.5 million-kva breakers were rebuilt to handle the larger power, and nearly 3 times as much interrupting capacity was built in the same tank. Next, the Tennessee Valley Authority required 7.5 and 10 million kva at 161 kv in 1951. Following this came the Ohio Valley project with its 25 million kva breakers at 345 kv (Fig. 13).

The increased interrupting capacity is by no means the only significant advance in circuit breakers. Although interrupting time seems to have reached a plateau at 3 cycles, reclosing time has steadily been improved. In the 1930's, reclosing times of 35 to 60 cycles were common. With increasing transmission voltages and the ever-increasing importance of service

Fig. 13. These 345-kv circuit breakers have an interrupting capacity of 25 million kva.

Fig. 14 (left). First dead-tank high-capacity outdoor compressed-air circuit breaker. A 138-kv unit, it has an interrupting capacity of 10 million kva. Fig. 15 (right). One pole of 15,000-mva SF_6 circuit breaker.

continuity, shorter reclosing times assume more significance. Today's breakers for transmission-line service commonly have reclosing times of 20 cycles or less.

Oil Circuit Breakers. While the ratings of oil circuit breakers have been increasing, the amount of oil used in these dead-tank breakers has decreased sharply. Improvement of interrupters during the past 10 years has allowed tank size to be reduced about 50%. Changes in the shape of the tank, such as the watchcase design developed in 1950, have further reduced this amount by 50% for breakers in the 230-kv class. In this connection, a factor of about four can be applied to in comparing the type GO breaker of 1940 and the type GW of 1952. The type GO had an interrupting rating of 2.5 million kva and needed 15,000 gallons of oil, while the type GW has an interrupting rating of 10 million kva and requires but 4,200 gallons of oil. This means less foundation cost and also simplifies the task of shipping large breakers.

Compressed-Air Breakers. Although oil breakers have largely dominated the high-voltage high-power scene for many years, other types of breakers are now coming into their own. One is the compressed-air breaker. For many years, the compressed-air breaker, while used here and in Europe, had definite limitations. The usual design for outdoor high-voltage apparatus used porcelain under air pressure for structural members and insulation to ground, which generally required separate, costly current transformers. A new approach is represented in a 138-kv 10-million-kva compressed-air breaker. The first of these units is now installed on the Consolidated Edison system in New York City (Fig. 14).

This new design physically resembles an oil breaker in external appearance. Each phase of the interrupter is contained in a separate steel tank in air at 250 psi. The operating and linkage mechanism is much like that of the oil breaker; when the breaker is tripped, a crossarm inside the tank moves downward driven by an accelerating spring, and pilots a trigger valve on each of two interrupters. This sets up a pressure unbalance across the main actuating piston, and the piston drops, opening the blast valve and drawing an arc in the orifice. The current is then shunted into a parallel resistor. The arc is interrupted by the blast of air from the tank through a second orifice in series with the resistor and out through the hollow conductor of the condenser bushing.

Changes in the geometrical configurations of the orifice and application of new materials in this type of interrupter have made the higher ratings possible. This type of breaker will find its greatest application advantages where oil storage, handling, and purification, and the attendant fire hazard are objectionable, such as in large metropolitan areas. Reduced maintenance time and expense are among the advantages of this type of breaker over oil breakers.

Sulfur Hexafluoride Breakers. Perhaps the most significant advance of the past 25 years is the introduction of a third major interrupting medium, sulfur hexafluoride (SF_6) gas. The unusual arc-quenching abilities of SF_6 makes it possible to design a breaker that combines the best features of oil and compressed-air breakers. Like oil breakers, the SF_6 breaker may have dead-tank construction, positive mechanical connection between all contacts and operating mechanisms, and bushing-type current transformers. Like compressed-air breakers, it is lighter than oil breakers and lighter foundations can be used. An impressive feature of this breaker is its quietness which, of course, is a particular advantage for residential areas.

In one design, each pole of the SF_6 breaker consists of a round horizontal tank, with a bushing rising verti-

cally from each end (Fig. 15). The interrupter is mounted axially within the tank, between the bushings. Minimum dimensions are possible because of the high dielectric properties of SF_6. The gas readily recombines after arc extinction, resulting in negligible gas decomposition and extending time between maintenance periods. The first breaker of this design will be a 230-kv 15,000-mva unit to be installed in 1960 on the Pennsylvania Power & Light Company's system. Larger sizes are anticipated for the future.

The Future. The future for circuit breakers depends largely on the needs of electric utility companies. If the economics dictate larger and larger concentrations of power and higher voltages, then circuit breakers with the necessary interrupting capacity and voltage ratings can be built. As matters now stand, breakers may be built to 600 kv, a rating likely to be sufficient for some time to come. Interrupting capacities of 50 million kva or more are within the realm of possibility.

The oil circuit breaker appears to have a definite limit in sight. Above about 460 kv, the oil circuit breaker ceases to be economical and unit size becomes too large. The compressed-air breaker seems to be best suited to congested areas where the use of oil is not desirable. Although larger ones can be built, the most likely province for the compressed air breaker seems to be in the general range of under 200 kv.

Of the three types of circuit breakers, the sulfur hexafluoride unit seems to hold the most promise for the future, especially for larger ratings. It is perhaps significant that the very first of the SF_6 breakers has an interrupting rating of 15 million kva at 230 kv, or 1½ times the interrupting capacity of the Grand Coulee breakers built in 1947. Certainly much can be expected of SF_6 breakers in the future.

CONCLUSION

Perhaps the most dramatic indication of progress made in power apparatus can be gained by making a comparison. What would be the situation if no technical progress had been made since 1938? To satisfy today's demands would require more than twice the number of generators, transformers, transmission lines, and distribution stations. In 1938, about 1.4 pounds of coal were required to produce 1 kwhr of electricity; today, only 0.65 pound is needed. In a representative power plant, six 1938-model electric generators would be required to provide the same output that one unit can produce today. And many more examples could be cited.

The progress to date in power apparatus has been possible only because the electrical industry has for many years sponsored one of the most extensive long-range research and development programs ever undertaken in this country. Today, however, limits are becoming apparent in both the materials and the forces with which we work. Planning for the future must be even more careful, even more thorough than in the past. Regardless of all other aspects, however, one fact is obvious: research and development must continue to lead the way by uncovering new knowledge and applying it to the power apparatus of the future.

Electric Power Transmission

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Courtesy Public Service Co. of Colorado

THE 75TH ANNIVERSARY of the AIEE is a particularly appropriate occasion to review and take stock of the developments in power transmission. A corresponding review by Prof. H. J. Ryan just 25 years ago traced the development of power transmission from its early beginnings and discussed how, among other things, the number of phases and the system frequency were chosen. At that time, the 300-mile 287.5-kv line from Hoover Dam to Los Angeles, Calif., was just being erected. The newly solved problem of lightning, system stability, and symmetrical components were still being digested and assimilated. The a-c calculating board had just been adopted and accepted as a tool for the solution of regulation, load, and reactive power flow and stability problems. The closely allied problem of synchronous machine transient analysis had also just completed its first great bound in understanding.

Today, in many respects, we are in an analogous situation. Just a few years ago, in this country 345-kv transmission and in Europe 400-kv transmission have become an accomplished fact. New problems have come to light or are receiving greater emphasis with these steps to higher voltage. Radio influence and corona loss have taken on added importance. Unforeseen and unpredicted outages caused by lightning have called for new analysis. The higher system voltages have also emphasized the economics attendant with low insulation levels. The improvements in lightning arresters that have made lower BIL's (basic impulse insulation levels) possible have focussed attention on the importance of switching surges. Automatic load dispatching for greater system economy is receiving greater acceptance. And, in the field of new tools, the digital computer, with its wondrous flexibility, is taking over many of the functions of the a-c board and is aiding in the solution of many of the new problems. Thus, just as 25 years ago a new step in voltage has been made and new problems were being solved, so also today the industry is faced with new problems not only of system design and characteristics but with the study of the characteristics of new equipment and its effect upon these problems.

Facing the industry are a large number of other problems—some structural or mechanical in nature, others purely electrical, and still others are combinations. It would be impossible in a review of this nature to discuss all of the important phases of transmission. The author will, therefore, select for discussions only those that he regards of greatest importance.

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SYSTEM VOLTAGES

IN THIS COUNTRY there is no standardizing body that has full responsibility for the standardization of system voltages. In 1949, the Edison Electric Institute (EEI) and the National Electrical Manufacturers Association (NEMA), after many years of surveying actual system conditions, issued a joint report that included a recommended list of preferred systems voltages. This report has since been issued under the auspices of the American Standards Association (ASA). The list of system voltages in the transmission range is reproduced in Table I. It will be observed that the nominal values are even multiples of 115 given in the second column. To each system voltage, a minimum and a maximum tolerable value has been assigned, the latter being in these cases 5% above the nominal value. The group responsible for this report has since been discharged and nobody has been designated to take its place.

For the international standardization of system voltages, a committee of prominent engineers has been appointed by ASA to reflect current opinion in the United States. When particularly important questions arise, such as the standardization of the 345-kv system voltage, it is necessary for this group to approach representative industry organizations having standardizing bodies to obtain decisions. There exists a very definite need for the establishment of a single group with ade-

Table I. Preferred System Voltages

Preferred Nominal System Voltage	Multiples of 115	Tolerable Zone	
		Minimum	Maximum
69,000	600	60,000	72,500
115,000	1,000	100,000	121,000
138,000	1,200	120,000	145,000
161,000	1,400	140,000	169,000
230,000	2,000	200,000	242,000

quate industry authority for national standardization in this field and to advise the United States representatives on international standardization.

In the case of the 345-kv system voltage, approval has already been obtained from the Standards Committee of the AIEE, from EEI, and from NEMA to this value for the next higher nominal system voltage together with the corresponding value of 362 kv as the maximum voltage in the tolerable zone. This value thus really has even greater standing than the other values, shown in Table I, that have general industry acceptance. Efforts are now in progress to obtain international recognition of the 345-kv system. With 2,300 circuit miles and 13 million kva of connected transformer capacity in the United States at this voltage there should be little trouble in obtaining this recognition.

In international standardization, although it has been possible to agree upon a list of numbers for the really important quantity, the "highest system voltage," it has been impossible to obtain agreement upon a list of "nominal system voltages"; that is, numbers that would be used merely to designate the systems. The principal obstacle is the fact that in the United States, the highest system voltage is 5% above the nominal and in most European countries 10%. It appears at the present time that this difficulty will be resolved by the subterfuge of dividing the systems into 60-cycle and 50-cycle systems, the former to have a 5% differential and the latter a 10% differential. In general, considerable argument or discussion over the nominal system values appears unimportant since, after all, it is merely the name by which the system is called. The crux of the situation is the danger of once having standardized upon a highest system voltage; then, if a nominal be chosen 5% below this value, some might insist upon a highest system voltage 10% above this nominal. And so the dizzy spiral of even higher and higher nominals would continue. It was just through such developments that the present systems in the United States came to be established in multiples of 115 in the higher range of system voltages and in multiples of 120 in the lower range of system voltages instead of multiples of 100.

Courtesy American Electric Power Company

Double-circuit 345-kv transmission line tower of the American Electric Power Company.

In the International Electrotechnical Commission (IEC) the next higher system voltage that has already received approval is the system having a 420-kv maximum value. Many European engineers refer to this system as a 400-kv system although the margin is then only 5%.

The question of still higher voltages will soon arise both in this country and abroad. In the United States, numbers that have been raised in these considerations are 460, 500, and 600 kv. There is always the question as to whether standardization should precede or follow actual reduction to practice. To expedite analysis of contemplated systems, it would be well for the industry to choose certain definite numbers so that different groups can talk in terms of the same numbers. And so, it is suggested that for discussion of future systems, the practice of even multiples of 115 for the nominal system voltages be continued and that above 345 kv, the next two voltages be 460 kv and 575 kv. Further, the maximum voltages in the tolerable zone should be 5% above these values or 483 kv and 603 kv, respectively. While the steps between successive voltages above 345 kv appear somewhat small, an overlay of 460 kv over a 230-kv system appears somewhat low and 575 kv would probably be more satisfactory. For single-site developments, the availability of the three steps 345, 460, or 575 kv from which to choose would be desirable and discourage injection of intermediate values.

INSULATION CO-ORDINATION

After the preliminary investigational stages, during which testing techniques with the impulse generator and the cathode ray oscillograph were being developed, in 1933 three impulse voltage waves were standardized; the 1×5, 1×10 and 1.5×40 microsecond waves. With time, the first two were dropped and the volt-time characteristics of apparatus became known in terms of the 1.5×40 wave. This information laid the groundwork for a sound philosophy of co-ordination of insulation and led, in 1941, to the establishment of a list of basic impulse insulation levels, usually abbreviated BIL. This list is given in Table II together with associated reference voltages. In most cases, these reference voltages correspond to a "preferred nominal system voltage" and are the system voltages for which the BIL would be applicable if the system were ungrounded. These

have come to be known as the "full insulation" values. During the past 10 years, these values have been under review by AIEE Standards Co-ordinating Committee No. 8 and the values indicated in the third column of Table II have been added and will probably be approved by the Joint Committee of AIEE, EEI, and NEMA. Reference voltages have not been assigned to the new BIL's by the present committee, partly because of the reluctance of the committee to associate a given BIL with any particular system voltage, partly because the small steps in insulation, percentagewise, would result in too many reference voltages and partly because the absence of ungrounded systems in this range would merely introduce a new set of fictitious system voltages.

Table II. Standard Basic Impulse Insulation Levels

Reference Class (kv)	1931 BIL Values (kv)	Levels Being Added by Present Committee
1.2	30	
2.5	45	
5.0	60	
8.7	75	
	95	
15	110	
23	150	
34.5	200	
46	250	
69	350	
92	450	
115	550	
138	650	
161	750	
		825
196	900	
230	1050	
		1175
287	1300	
		1425
345	1550	
		1675
		1800

The application of these values to locations that are exposed to hazards of lightning assume the presence of a lightning arrester that will limit the degree of overvoltage. Grounding of the system permits the installation of a lightning arrester of lower rating than that which would be permissible on an ungrounded system. Lower BIL's can be justified on such systems. Hence the development of the term "reduced" insulation, which means reduced with respect to the insulation that would normally be applied on the system if it were ungrounded. For a 345-kv or higher system voltage, speaking in terms of reduced insulation of one or two steps can well become ambiguous because of the absence of an accepted reference voltage class.

Through the co-operative efforts of the manufacturers, industry characteristics of arresters have been published since 1937. Only nominal improvements were evidenced up through 1953 but in 1955 discharge characteristics showed a reduction of some 20%. Prior to this date, with sufficiently good grounding conditions, it was customary to apply 80% arresters which permitted a reduction of one step in transformer insulation. At about this time, recognition of better than 80% grounding conditions which permitted arresters of lower rating together with the improvement in arrester characteristics led to the reduction of transformer insulation of 1½ and 2 steps. The economic justification of insulation reduction is a function of the system voltage. The saving in insulation at 69 kv and below is usually not warranted. Table III shows the present practice in the United States with regard to reduction in insulation.

Presently available arresters justify even lower BIL's if the protection against impulse voltages were the only criterion. Consider, for example, a location in a 230-kv system where the grounding conditions are such that a 75% arrester can be installed. Such an arrester can limit the impulse voltage across its terminals to a crest value of 470 kv with an assumed discharge of a 5,000 ampere 10×20 microsecond wave. Allowing a margin of 20% plus 30 kv for such factors as excessive discharge current, separation between arrester and protective equipment, tolerances in manufacture and aging of insulation results in a voltage of 594 kv which is considerably less than the 2-step reduced level of 750 kv. What are the fears, real or imaginary that hinder one from installing lower insulation levels? There are other considerations, principally considerations affecting switching surges which will be discussed later and the question as to whether the insulation will stand up under long application of the power-frequency voltage. The industry has accustomed itself to the exceedingly fine performance record of transformers protected by arresters so much so, that the old practice of providing spares has been largely abandoned. Re-establishment of this practice could quickly annul any savings provided by lowering the insulation to hazardous values.

SWITCHING SURGES

THE TERM "switching surge" has come to be applied to the abnormal voltages accompanying any change in circuit conditions and is not just applied to a switching operation. These changes may involve short circuits or their clearing, a change in the number of transmissions lines, interruption of charging current or magnetizing current, fuse operations, and the like. In general, these phenomena are attended by slower changes of voltage than the impulse phenomenon associated with lightning disturbances. But in the limit, these frequencies and rates of change can well approach impulse conditions.

Over the years, any unexplained insulation failure

Table III. Estimates of Per Cent Usage of Reduced Level Insulation of Transformers for Units Above 15,000 kva

System Voltage in kv	Full Level	One Step Reduction	1½ Step Reduction	2 Step Reduction
115	(550)	(450)	(a)*	(a)*
Past	80%	20%	—	—
Future	60%	40%	—	—
138	(650)	(550)	(a)*	(450)
Past	35%	60%	—	5%
Future	15%	60%	—	25%
230	(1,050)	(900)	(825)	(750)
Past	5%	25%	65%	5%
Future	0%	15%	50%	35%
345	(1,550)	(1,300)	(1,175)	(1,050)
Past	0%	0%	90%	10%
Future	0%	0%	40%	60%

*(a) Not offered.

High-altitude corona test line of the Public Service Company of Colorado.

not occurring during a lightning storm, for lack of any other convenient explanation, was attributed to a switching surge. This was merely an indication of the confused state in this field. While much has been learned during the past 25 years, much still remains to be done, particularly with respect to assigning numerical values to the effects.

In the application of interrupting devices the significant property of the surge is the rate of rise of the voltage across the terminals. This quantity is understood quite well and its effect upon the operation of interrupting devices has been evaluated within practical limits. At the present time, the principle concern is with regard to insulation co-ordination and application of lightning arresters. This applies not only to the surges that occur in practice, but also to the ability of insulation to withstand potentials of this character.

Until recently, little importance had been attached to switching surges, particularly if lightning arresters were installed. Of recent years, the improvement in arrester characteristics under impulse conditions transfers the emphasis of insulation co-ordination to switching surges. And so the question asked today is "Can switching surges be developed within the system which would have such characteristics that the arrester would not protect the insulation, or if it does protect, can it do so without injury to itself?

The problem is being attacked from several angles. Much work is being done on systems in miniature, largely because of the ease with which a wide variety of system conditions can be achieved and because of the possibility of studying projected systems before their actual construction. The use of miniature systems also permits the study of special critical ranges of system parameters and the adjustment and analysis of the effect of the number of circuit breaker restrikes. However, staged tests or the results of long time tests on actual systems by means of automatic recording equipment is perhaps of even greater importance because it eliminates all question of adequate representation of the actual conditions under which the equipment is called upon to operate. Perhaps of even greater significance is the service experience of the co-ordinated equipment, but one might not wish to risk the hazards of operation of an important system with unusually high reductions in insulation while accumulating such experience.

There has been some reluctance, even on the part of those who have had excellent experience with one step reduction in insulation protected by 80% arresters, to accept further reduction in insulation protected by 75 or 70% arresters. This reluctance is based largely upon an indefinable fear that in some manner the arrester will not protect the transformer against switching surges. It should be pointed out in this connection that the breakdown and discharge characteristics of arresters to switching surges are proportional to their ratings. Therefore, the arrester should provide the same degree of protection as for the 80% case. The only additional hazard is the greater number of arrester operations. The capacity of the 75% arrester to handle switching surges is only slightly less than that of the 80% arrester. For arresters of that particular type which have demonstrated by actual service experience their ability to handle switching surges in 80% applications, there should be no additional hazard for 70 or 75% applications. The concern should not be with regard to applying lower insulation with arresters of correspondingly lower rating, but whether arresters of all kinds, 80% as well as 75 and 70% are not being subjected to more severe operating conditions.

POWER CAPABILITY

IN THE PAST 25 YEARS, intensive theoretical study of power transmission and apparatus development has practically doubled permissible circuit loadings. High-speed relays and circuit breakers and high-speed reclosing account for the major portion of the gain. A convenient quantity to measure circuit loading is the "surge impedance loading (SIL)." This is the resistive load which a line of zero resistance can carry an indefinitely long distance at constant voltage. The inductive kva just equals the charging kva per unit length. Because of the usual construction of lines, it is numerically equal to 2.5 times the square of the line-to-line voltage and for 230, 345, and 460 equals 132,000, 300,000, and 530,000 kw. If the conductor is a twin-conductor bundle, the SIL is approximately 25% higher. The charging kva per 100 miles happens to be about 20% of the SIL.

When the resistance load is replaced by synchronous equipment then the possibility of loss of synchronism between the two ends of the system is injected. This constitutes the stability problem. SIL can still be used as a basis of rating by applying factors that depend upon the distance. Thus, a line can be operated at approximately its SIL when the distance is 300 miles and at 1.4, 0.76, and 0.58 its SIL when the distances are 200, 400, and 600 miles, respectively. Like all rule-of-thumb relations, this likewise is an oversimplification. Such factors as the number of parallel circuits, compensation by series capacitors, sectionalizing points and system layout, all affect the actual permissible loading.

However, using this simple rule, it is found that for 345 kv and 460 kv respectively, using a bundle conductor, the loading of a single line to transmit 300 miles is approximately 375,000 kw and 660,000 kw, respectively. In view of the rapidly increasing size of generating stations and the increasing costs of rights-of-way with the urgency to keep the number of lines to a minimum, the need for capabilities of this order is quite evident. Even higher capabilities with consequent greater voltages may ultimately be required.

D-C TRANSMISSION

FROM THE BEGINNING of the electric power industry, a struggle has existed between advocates of a-c and d-c. With the invention of the incandescent lamp, Edison developed the continuous current 220-volt 3-wire system which led to the d-c supply systems of the cities of New York, N. Y., Buffalo, N. Y., and Chicago, Ill. This system greatly limited the radius within which such service could be supplied. Shortly thereafter Westinghouse, recognizing these limitations, took the Gaulard–Gibbs transformer and developed its possibilities resulting in the 2-wire a-c system which greatly expanded the distance within which service could be supplied. This transformer and its immediate successors form the basis upon which our present-day transmission systems rest. With time, the d-c advocates lost completely and, today, the d-c supply even in the big cities is being supplanted by a-c. But ever since those early days there have been enthusiasts, who, recognizing that an a-c line had to be insulated for the peak of the voltage whereas the working value is the rms value and recognizing also that vars must also be transmitted, have continued to advocate d-c. Today, these advocates for such and other reasons are victorious in a limited area.

Aside from the Thury system in France, there was little interest in d-c transmission until the development of the high-voltage gas-filled tube. Many economic comparative studies concerning open-wire transmission have been made in this country and in Europe. In fact, the first such study of which the author is aware was made by his associates in 1931. This showed that for the probable cost of the terminal equipment, which was not then developed, d-c transmission would not be economic except in blocks of power in excess of 300,000 or 400,000 kw transmitted a distance of 350 miles. Similar studies made both in this country and in Europe with presently available cost data confirm this general conclusion. It is not surprising, therefore, that in the United States, with the availability of either water-power resources or good fuel within relatively easy reach of load centers, d-c transmission has not been found attractive. The most likely location where d-c transmission by aerial lines will find approval are those where the naturally available energy supply lies at distances in excess of those just mentioned.

On the other hand, transmission of energy by buried or submarine cables by a-c has very definite distance limitations. Presently available cables reach their thermal limit merely to supply their charging characteristics at only 25 to 35 miles of cable. But with d-c, the capabilities are greatly enhanced. It is for this reason that two of the earliest practical, installed or projected, d-c projects utilize submarine cables.

Historically, the earliest work on a large scale was that done by the Swedes and Germans. The Swedes were interested in the transport of energy from the water power sites in the north to the utilization points in the south, a distance of some 500 or 600 miles. Unfortunately, when the need arose, the terminal equipment had not yet been developed and a-c lines of 380 kv were constructed. But now according to Messrs. Jancke and Smedfelt, "It has been found relatively difficult to adopt a d-c system of this kind ($\pm$400 kv) to the existing Swedish network in an economic manner. It is not possible to construct rectifier transformers for connection to an a-c voltage of 400 kv. . . . It would be necessary to allow for a 138-kv supply, in which case, the capacity of the station must not exceed 1,000 megawatts (mw). In these circumstances, a d-c transmission would prove somewhat more expensive than a high-voltage a-c transmission." However, Sweden does possess the first large-scale d-c system, that involving cable transmission at 100 kv and 200 amperes a distance of 60 miles through a single submarine cable with the return in the water. This connects the mainland with the island of Gotland. A further stage is now under discussion for installation in about 1962.

Germany, during World War II, also undertook a vast development of equipment for d-c transmission and had almost completed a system to transmit power from Berlin to the Elbe a distance of 70 miles. This project was undertaken in part for strategic reasons as the line was a buried cable. As an outgrowth of this work, the Soviet Union has completed an experimental system using buried cable, too, that extends from Moscow to Kashira, a distance of 70 miles. The voltage between conductors is 200 kv and the line current is 150 amperes.

According to Soviet engineers, the Soviet Union now has under construction the initial link of an ultimately vast d-c transmission system. This link will connect the Stalingrad plant and the Donbass with a 2-conductor $\pm$400-kv d-c line, a distance of 300 miles, capable of transferring 750 mw in either direction. This is intended to provide for the seasonal fluctuations between the two hydroelectric systems. In the event of failure of one line, it is intended to continue transmission through the other with the earth as return, thus dropping only one half of the capacity of the line.

Construction is also about to begin on a d-c link across the English Channel between Lydd, England, and Le Portel, France, a distance of 34 miles. The line will consist of two single-core cables of the lead-covered impregnated type, without gas pressure. They will operate at $\pm$100 kv, 800 amperes and will be separated by not more than 550 yards. This latter requirement is to minimize magnetic deviations on ships' compasses. Power exchange will be in either direction with automatic reversal, if required.

There are many problems that are peculiar to d-c transmission but which seem to be well on their way to solution. Fundamental to this system is the tube for conversion from a-c to d-c and then back again from d-c to a-c. For the Channel project, each group of 6 tubes will operate at 100 kv and 800 amperes. In the Stalingrad–Donbass project, each tube will be good for 130 kv and 900 amperes. Arc backs are cleared by automatic blocking and deblocking equipment without interruption of service. Since d-c circuit breakers are not available, the line and conversion equipment is regarded as a unit and line failures are cleared by the control grids of the tubes. The lightning arresters are not required to interrupt the discharge current since the current flow is interrupted by operation of the control grids.

A definite disadvantage of d-c transmission is its inflexibility with regard to adding generation points or load take-off points, each location requiring its own conversion equipment. Electrolysis would certainly be a serious problem in congested areas, if the load current were permitted to flow through the earth under emergency conditions. Adequate filtering equipment must also be provided to prevent harmonic voltages from penetrating into the a-c distribution system. This is of importance because of the effect upon telephone communication systems and also because of harmonic overloading of capacitors. Inasmuch as reactive kva cannot flow along d-c lines, special provision may be necessary to supply reactive kva. Although the loss caused by corona at a given conductor surface gradient is less for d-c than for a-c, the radio noise influence voltage (RIV) may not be. Additional data are required on this point.

A 350-kv folded-pole lightning arrester.

A d-c link may be of advantage in some cases when the two systems to be joined are of different frequencies or where a flexible nonsynchronous tie is desired. H. Witt of Sweden at the 1958 meeting of Conference Internationale des Grands Reseaux Electriques (CIGRE) in Paris, France, stated that it seems economically and technically feasible to keep switching overvoltages on high-voltage d-c lines small (1.70) compared with a-c lines (2.5). It appears then that holding of the normal service voltage may be the controlling factor. Tests made in a fog chamber indicate very little difference between a-c and d-c upon the ability of insulators to hold voltage under these conditions. Gertsik, Korsuntser, and Nikol'skii report that one should expect practically no difference in the degree of contamination as between d-c and a-c line insulation.

LIGHTNING PROTECTION

LIGHTNING has been one of the most formidable enemies of power lines and equipment. Protection against its effects has taken entirely different courses for lines and equipment.

In the early days of transmission, it was believed that nothing could be done to guard a transmission line against flashover in the event of a direct stroke. In 1930, the direct stroke theory was proposed by Fortescue and therefrom evolved our present theories and practices regarding line protection. This theory required first the installation of a ground wire or ground wires so located with respect to the conductors as to shield them effectively from the stroke and, second, a sufficiently low tower footing resistance so that on passage of the stroke current, the tower structure and ground wire system were not raised unduly in potential above ground. In this area, during the past quarter century, the industry was largely concerned with refinements in the application of this theory. In the mechanism of the stroke itself, Schonland contributed enormously with his investigations. Other investigators likewise were active in collecting statistical information concerning the probability of occurrence of stroke currents and other pertinent characteristics. Some controversy existed as to whether the tower in this theory should be represented by a surge impedance or as a lumped inductance. Actually, the difference in results using the two methods was small and completely overshadowed by considerations affecting shielding and tower footing resistance. Very good agreement was obtained between predicted and actual outages. The industry was quite satisfied with its available theories of lightning protection and an acceptable method for calculating the lightning performance was developed by the Lightning and Insulator Subcommittee of the AIEE in 1950.

About 1955 and 1956, information became available concerning the performance of the 345-kv lines of the American Electric Power Co. and the Ohio Valley Electric Co. and the 138-kv lines of the Commonwealth Edison Co. The former were 148 feet tall and the latter 108 feet and both had but a single ground wire. The outages were about 10 times the values predicted by the

A 90-mva series capacitor installed on the 230-kv lines of the Bonneville Power Authority.

AIEE method. A flurry of papers and an intensive study—analytical, laboratory, and in the field—followed spreading of this information. New theories and opinions were widespread. Some attributed the poor performance simply to poor shielding. The controversy was reopened as to whether the tower should be represented by a lumped inductance or a surge impedance. Others felt that the wave front was shorter than that indicated by presently available data and re-examined old data to support the opinion. A new prestrike theory was also proposed to support this opinion. Others felt that the AIEE method was based upon an insecure theoretical basis and proposed alternate analytical treatments based upon field theory to support or reject some of these concepts. Even in the latter group there were differences concerning the effect of the charge in the stroke channel above the tower for the same stroke assumptions. The author has also spilled some printer's ink in these controveries. And so the matter of lightning protection stands today. With the intensive work now in progress, the situation should crystallize within the next few years and the phenomenon be clarified and explained to the general satisfaction of the industry.

The protection of the equipment connected to the line centers around the lightning arrester. The substation and at least one or two spans of the line out from the substation are usually shielded by ground wires to guard against a direct stroke near the protected apparatus. The lightning arrester need provide protection only for the induced voltages or surges coming in from the line. The influence of the arrester upon the apparatus insulation is discussed under the subject of insulation co-ordination.

SLEET MELTING

THE ACCUMULATION of sleet and ice under weather conditions around freezing temperatures can be particularly troublesome. The formation of ice not only produces extra-heavy loads, which under extreme conditions may cause a break in the conductor or cause tower damage, but as the ice melts it may break off in large chunks that unload the conductor and cause it to whip into another phase, thereby, producing a short circuit. Also, with certain wind conditions, sleet formation appears to be conducive to the development of galloping conductors, On double-circuit towers, both of these effects require greater spacing between conductors which results in longer arms and higher and heavier towers.

To guard against such conditions, some utilities resort to sleet melting. The line in trouble may be taken out of service and short circuited at one end while reduced voltage from another bus is applied to the other end to circulate melting current. In other cases, parallel lines are disconnected so that the endangered line can be overloaded. Melting currents of the order of two to three times rated are required and these must be applied from 20 minutes to 1½ hours, depending upon the circuits available. The installed circuit breakers and line traps must be suitable for these currents and these durations.

The detection of the formation of sleet constitutes an important problem. It should be much easier to prevent its formation than to melt it after a thick layer has formed on the conductor. At least one company uses, as a warning of the formation stage, the variations in the attenuation of the carrier-current.

CORONA LOSS AND RADIO INFLUENCE

EACH NEW STEP in system voltage has been preceded by an intensive study of corona, using for this purpose the particular types of conductors that it is contemplated will be used. This was true for 230 kv, 288 kv, 345 kv, and 380 kv. During the past quarter century, the work in this country was concerned with 345 kv and in Europe with 380 kv. For the earlier steps, interest centered about loss only but a new factor, radio influence (RI),

Long time exposure of corona formations on 10,000-foot altitude test line of Public Service Company of Colorado.

Table IV. Size of Single Conductor and Subconductor of a Bundle That Will Give Comparable Radio Influence

Nominal System Voltage in kv	Number of Conductors in Bundle			
	1	2	3	4
	Conductor Size in Inches			
345	1.7	1.0	0.75	0.5
460	2.5	1.5	1.1	0.8
575		2.1	1.5	1.1

has entered the picture. With the imminence of a new step of 460 kv and possibly 575 kv, a resurgence of interest has developed concerning corona. While the work done in this country on 345 kv and in Europe on 380 kv should provide sufficient information to predict the size of the conductors that would be satisfactory for 460 kv, still the users prefer to experiment with the actual conductors and type of construction that will be used.

Aging and weather have a great influence upon both corona loss and RI. The loss for any particular locality should be based upon a weighting of fair and foul weather data in accordance with the U.S. Weather Bureau records from that vicinity. While the loss should not be ignored, recently greater emphasis has been placed on RI characteristics in choosing a conductor. A satisfactory RI level is dependent upon the ratio of the noise level to the signal strength reception for the particular locality and also upon the density of population of the region through which the line passes. Table IV gives a general idea of the size of conductors that would provide about the same level of RI. These are quite typical of operating lines in this country and Europe. Altitude must also be considered in selecting the conductor for a particular voltage. Tests are now in progress in Colorado at an altitude of 10,000 feet. The preliminary data indicate that a single conductor of a particular diameter can operate at this altitude at about 85% of the voltage at which it could operate at sea level for the same RI. In addition to their corona advantages, bundle conductors also possess lower reactance for a given section of conductor, the reduction increasing with the number of subconductors. Snow, sleet, and ice loading on the other hand can be greater.

A LOOK INTO THE FUTURE

THE ROLE OF THE SEER is never comforting. The author has witnessed over the past 40 years, the developments in transmission in such areas as system stability, symmetrical components, impulse testing and insulation co-ordination, corona loss and radio influence, and lightning research; and having made some modest contributions himself in these fields, a peek behind the curtain into the next 25 years, which is one of the directives to the authors of this group of articles, does not seem to be too formidable a task. In addition, a glance at the mortality tables does not give the author much concern that he will be present at the end of that time to be confounded by the brashness of his predictions. That is one advantage of assigning such tasks to the older men of the industry. So with that assurance, the author will venture a few predictions concerning the course of power transmission in this country during the next 25 years.

During the early part of the past quarter century, the need for long-distance transmission arose largely from the transportation of power from water power sites and less from interconnection. Except in the far west, where water-power resources are still available, the emphasis is now transferred to interconnection and the transport of energy electrically from locations adjacent to mouth-of-mines and cooling water supplies to load centers. As systems become more closely knit, stability becomes less of a problem. Economy of transmission, load control, and frequency control emerge as more important. And so, for the utilization of water-power sites and mouth-of-mine plants one should see in the early part of the coming quarter century 460-kv transmission and in the latter part 575-kv transmission. The physical necessity of providing an adequate outlet to the much larger central stations of the future constitutes a strong force to increase transmission voltages.

In spite of the now generally accepted 5% by which the highest system voltage exceeds nominal, controversy will arise as to whether this should be 5% or 10% in new projects. It is difficult, in the presence of the understandable desire to have the highest system voltage in operation, to sell the idea that the highest system voltage is the design voltage and that the "nominal" voltage is merely the name by which the system voltage is designated. Any increase above this tolerance, in view of the national and international agreement on highest system voltages, must be at the risk of the user.

Barring the justification of d-c transmission lines on a socialized basis rather than economic grounds, it does not appear that such lines will be built in this country during the next quarter century. The availability of competitive atomic energy plants will ease the pressure for long-distance transmission projects. On the other hand in other parts of the world, such as in the USSR, it might be economical to transmit power from the enoromous water falls of Siberia to the load centers in Europe. Where a submarine cable is a necessary link in the system such as between Norway and Denmark or between southern and northern islands of New Zealand, d-c transmission possesses distinct advantages over a-c transmission.

Within 10 years, large atomic-fueled plants will become competitive with coal-fueled plants in some parts of the country. And, as this trend develops, it will have an important influence upon the necessity for long-distance transmission of power, either a-c or d-c.

No clairvoyance is required to state that the intensive studies of the lightning problem by so many groups will, in a few years, result in a clarification of the fundamental phenomenon involved. This should lead to new means for alleviating the trouble.

Inhibiting the formation of sleet or minimizing its effect would be very beneficial on reducing the cost of towers. Perhaps such means can be devised.

There is no reason for believing that the ultimate in lightning arrester development has been achieved. Further improvements can envision even lower insulation levels than are presently being used.

While the future possibilities of digital computers are being discussed elsewhere in this issue of *Electrical Engineering*, the role of such computing devices in the design and operation of transmission lines must be emphasized.

Certainly, in other countries (whether it be private power, public power, nationalized utilities, or communized power), the utilities are doing more detailed research than in this country. Here the policy, with some exceptions, is to let the burden of research and the development of new ideas rest upon co-operative programs between the utilities and several manufacturers. If this situation is to continue, and it has worked eminently well in the past, then some inducement must be offered those organizations to enable them to carry this heavy burden.

High-Voltage Testing Techniques

J. H. HAGENGUTH
FELLOW AIEE

NUMEROUS TECHNIQUES for use in acceptance testing of apparatus have been developed over the past 25 years. It is not possible to cover, because of lack of space, the various devices that may be used in high-voltage laboratories for development work, except in a very general way. At the end of this article, a list of papers most easily accessible to American readers is included. In addition, rather comprehensive bibliographies are available.[1–3] There have been many investigators who have made important contributions but are not mentioned because of the necessity for keeping references to a reasonable length.

GENERATION OF HIGH VOLTAGE AT POWER FREQUENCIES

HIGH VOLTAGE at power frequency is obtained by stepping up a low-voltage supply by means of transformers. Transformers have been built with a nominal output voltage of 1,200 kv[4] in a single unit. The general practice, however, seems to be the cascading of several units with individual transformer output voltages ranging from 200 to 750 kv because of greater flexibility in laboratory use. Fig. 1 shows five 350-kv transformers connected in cascade for a total output voltage of 1,750 kv rms to ground. Fig. 2 shows the diagram of connections used in these transformers. There are many variations used in these connections by various designers. If n is the number of units in cascade, the output voltage E is approximately equal to $n \times e \times$ ratio of one of the units. It has been reported that a $3 \times 750\text{-kv} = 2{,}250\text{-kv}$ cascade is installed in an outdoor high-voltage laboratory in Moscow, USSR. Such high voltages are normally used only for development and research work and, as such, are naturally of considerable value to the power industry.

The excitation voltage for the testing transformers may be obtained through regulators directly from the supply networks, or from separate motor–generator sets. In either case, smooth control of the voltage is highly desirable for accurate test results. The wave shape of the test voltage should be sinusoidal and reasonably free of harmonics.

GENERATION OF HIGH IMPULSE VOLTAGES

A COMMON CIRCUIT used with some minor variations in detail is the Marx circuit,[5] shown in Fig. 3. On top is a composite diagram. In the center are shown the elements active during the process of charging the capacitor banks up to the applied direct voltage. On the bottom are shown the elements active during the discharge period when the capacitor banks are connected in series by means of the sparking of sphere gaps. The output voltage is then about equal to the charging voltage times the number of banks. Fig. 1 shows, at the right, the two 5,100-kv generators of the High Voltage Laboratory of the Power Transformer Department of the General Electric Company in Pittsfield, Mass. These generators are built on the principle of Fig. 3. Wave shape control with these units is largely obtained by means external to the generators, primarily to obtain necessary flexibility for testing specimens of widely varying impedance characteristics and to maintain the required wave shape in all cases. Variations in the arrangement of circuit constants have been described.[6] Many methods of calculation for determining the output voltage of impulse generators have been developed.[7, 8] Very simple equations may be used for capacitive-type test specimens and the standard wave.[9]

Many impulse generators of 3,000 to 4,000 kv out-

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put voltage now are in use for impulse acceptance testing of transformers. Generator constants for tests on transformers, in order to obtain the correct wave shape, may be determined most readily by means of the electric transient analyzer[10] or recurrent surge oscillograph.[11] This is a low-voltage impulse generator with variable capacitance, resistance, and inductance in order to simulate the similar constants of the actual impulse generator. Such a generator may be discharged once during each cycle of the low-frequency supply voltage and the output wave is displayed on a sealed-off hot cathode-ray tube and can be analyzed directly. Because of the high repetition rate, a relatively low cathode voltage may be used even for very fast phenomena. It is a most useful tool for transient investigations of all kinds.

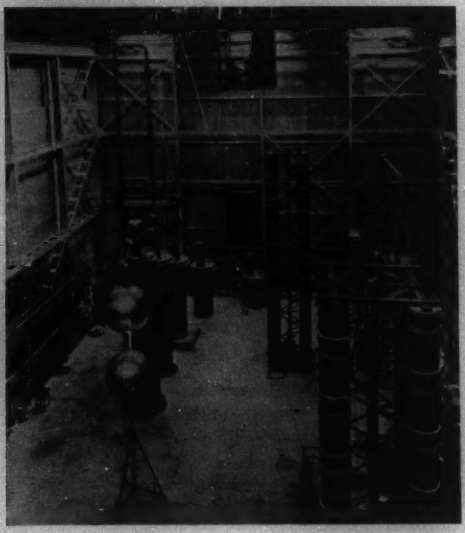

Fig. 1. A 1,750,000-volt (a-c) cascade connection of five 350,000-volt testing transformers with sparkover at 1,200,000 volts of the 200-centimeter sphere gap.

With the rapid growth of system voltages in the early part of the century, the necessity of insulating transmission lines and terminal equipment required continuously higher test voltages, both for development and acceptance testing. The development of test equipment for higher voltages almost always seemed to precede development of the measuring devices. Thus, the major task consisted in agreeing on such devices and their accuracy. Since insulation flashover was recognized as being dependent on crest voltage, the only applicable device was some type of gap where potential transformers were not available.

SPARK GAPS

Originally needle gaps were used which, however, were awkward and, because of the large influence of humidity and of the sharpness of the points, gave somewhat erratic results. In 1913 Chubb and Fortescue[12] and in 1914 Peek[13] gave data on sphere gaps which seemed to be independent of humidity and more consistent in response, and in 1914 calibration curves for sphere gaps were adopted by AIEE for spheres having diameters of 6.25, 12.5, 25, and 50 centimeters. In 1928[14] the AIEE standard curves were extended to include 2- and 75-centimeter spheres. It is believed that some of the higher voltages were based on calculations according to Peek.[15] He assumed that the maximum gradient at the sphere of radius R was constant in the range of spacing $S = 0.54\sqrt{R}$ and $2R$. From calibrations on the smaller size spheres a field factor was then calculated to fit the calibrated curves. Because of the good fit between values thus calculated and the calibration values for some of the smaller size spheres, extrapolation was extended to 100, 150, and 200 centimeters as the demand for impulse testing at higher voltages increased during the 1920 to 1930 period. At the end of this period, several investigators found it impossible to check voltages with different size spheres,[16] and a marked polarity effect[17] was found at some spacings used in the tests.

All of this work indicated that further study was needed to improve the accuracy of the sphere gap for more precise measurements, particularly for impulse applications. Calibrations were made in the United States by Meador,[18] Bellaschi and McAuley,[19] and others; in Great Britain by Edwards and Smee[20] and Davis and Bowdler[21]; and in Germany by Elsner, Dattan, Jacobi, Hueter, and Binder and Horcher.[22] The American work was adopted in 1936 in a committee report[23] and incorporated in AIEE Standard no. 4 in 1943. A paper by Dr. S. Whitehead[24] describes the methods used to arrive at revised International Electrotechnical Commission (IEC) values superseding IEC rules for the use of sphere gaps (Publication 52). These revised values apparently were used for later IEC recommendations 8(Central Office)601. They check well with the AIEE values from AIEE Standard no. 4 (1953) in the range where actual calibrations were available, i.e., for spheres up to 100 centimeters in diameter even at large spacings. However, the extrapolations used for the large spheres (150 and 200 centimeters) resulted in considerable disagreement for these sizes at large spacings with actual calibration tests.

International work was resumed on this question in 1954 by IEC. New calibrations with impulse on 50- and 100-centimeter spheres, and comparison with field factors obtained in the electrolytic pond,[25] showed good agreement with AIEE Standard no. 4 (1953) values but also indicated that the distance from the sparking point of the high-voltage sphere to the horizontal ground plane in a vertically arranged sphere gap, with one sphere grounded, is a rather critical dimension. These field factors also show that comparison calculations between sphere sizes based on the sparking gradient and Russell's field factor may be in considerable error at

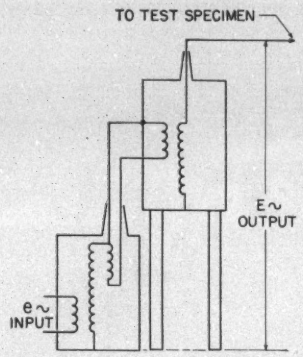

Fig. 2 Diagram of connections for GE cascaded transformers.

the large spacings. Calibration values, therefore, are preferable for assigning sparking potentials to sphere gaps. The result of the sphere gap calibrations was to establish two curves of sparkover voltage for each sphere diameter, one applicable for low-frequency voltages and negative impulse, the other for positive impulse voltages which are higher at the large spacings. The sparkover voltage is dependent on the air density and correction factors, and methods of correction are given in the various standards. There is also evidence that humidity has a small effect.[26] Sparkover voltage increases with increasing absolute humidity. While the difference in sparkover voltage may be as high as 3% in the range encountered during testing, it is not possible to standardize a humidity correction without further work.

In spite of the relatively high possible errors and some of the uncertainties remaining, the sphere gap has been the work horse for high-voltage measurements and is still considered as the primary standard with which other measuring systems may be compared to determine their suitability. This is somewhat incongruous because for many of the sphere-gap calibrations at low frequency, for instance voltmeter coils, capacitance-type dividers with crest voltmeters and other nonstandard devices were used to establish sphere sparkover voltage; likewise for impulse, dividers of various kinds were used with cathode-ray oscillographs.

To establish the consistency of data from different sphere calibrations, a number of experimental calculation methods have been developed besides that of Peek and Whitehead. Bellaschi[27] related the average (measured) gradient at sparkover to a function of spacing S/diameter $D = f(S/D)$ and $\log_{10} D$ and obtained good correlation. Ver Planck[28] evolves an equation where the sparkover potential $U = K(S\delta)^{\alpha}$ when K and α are parameters given as function of S/D based on the experimentally available data. Whitehead's calculations[24] are based on the maximum sparking gradient obtained with Russell's field factor and the assumption that, for very large diameters, the fields should become uniform and, therefore, the equation should become that of the uniform field. Thomas[29] has expanded these calculations, introducing uniform field equation values given by Bruce[30] and finds that his approach checks the IEC and AIEE values well. It suffers, however, from the use of Russell's field factor which is constant for a given S/D, while actually the field factor for $S/D = 0.7$, for instance, varies about 5% in the range of height of spheres above ground for spheres gaps of different diameters as recommended by IEC.

Much work was done to determine the influence of irradiation on the sparkover voltage of sphere gaps, and AIEE Standard no. 4 requires artificial irradiation of sphere gaps for measuring voltages up to 50 kv. Investigators[31] have found that positive polarity impulse sparkover voltages are reduced almost to that of the negative polarity by the use of irradiation, preferably in the form of radioactive materials inserted into the high-voltage sphere near the sparking point. However, since most calibrations used for AIEE and IEC tables were made without artificial irradiation sources other than the natural irradiation existing in testing plants, irradiation requirements for all spheres would need a complete recalibration of a number of spheres, a process which does not appear justified at this time. The accuracy of the sphere gap for low-frequency and impulse measurements is considered to be quite good, errors of $\pm 3\%$ being given in various standards. In some, this error is considered for gap spacings up to 50% of the diameter only. However, if necessary precautions are taken[25] and space is available, this same error is applicable up to full diameter spacing.

The sphere gap has attained its favored position because it has been long in use, is inherently a simple device, is not subject to gross errors, is available for low frequency and impulse voltage measurements, and because its function can be more easily understood by

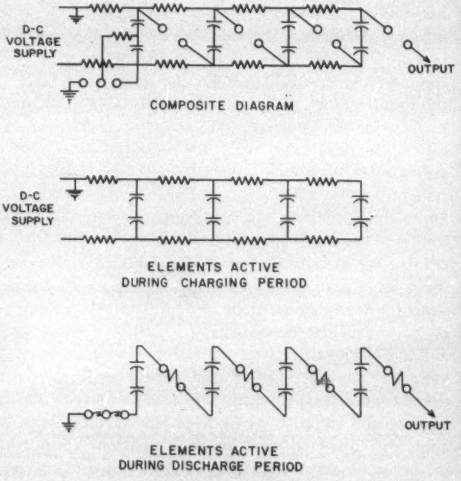

Fig. 3. Connection diagram of a Marx-type impulse generator.

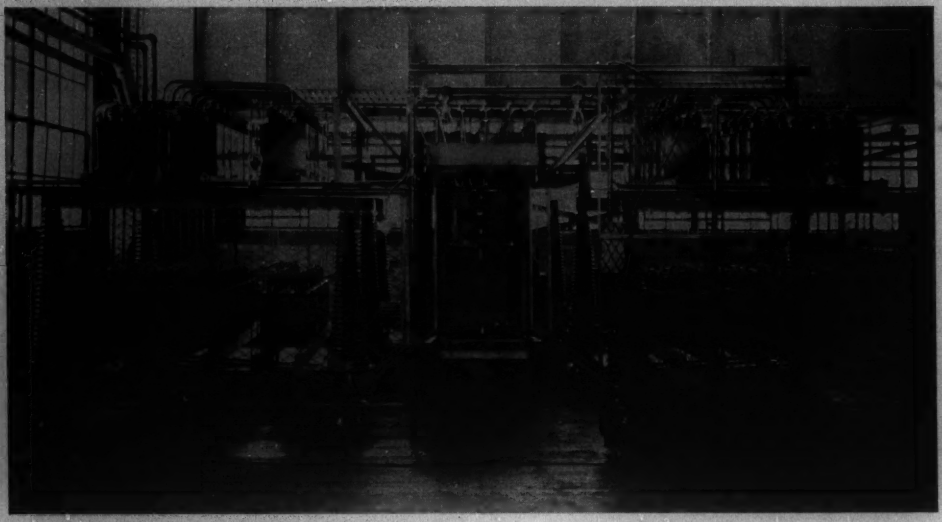

Fig. 4. High-current generator for 265,000 amperes discharge current at 50, 100, 150, and 300 kv.

most engineers than some of the other more complicated devices. However, no international agreement has been reached on calibration values for sphere gaps. At present, IEC Document 42(Central Office)3 is being circulated for approval by the various national committees of IEC under their six months' rule.

IMPULSE VOLTAGE MEASUREMENTS

PROBABLY the most rapid advance was made in the production and measurement of impulse waves. While impulse equipment was used in 1913,[15] its use was on a minor scale and strictly as a laboratory tool, principally because of inadequate instrumentation and lack of a complete understanding of all the circuit constants in the impulse generator discharge circuit and consequent inability to calculate the wave shape accurately. Invention of the parallel-charge series-discharge impulse generator by Prof. Marx[5] in 1923, as well as successful construction of an operational cathode-ray oscillograph by Dufour[32] in 1922 and its rapid adaptation and modification in various industrial laboratories,[33, 34] greatly increased the ease and accuracy of making impulse tests on a larger and more consistent base. Work to develop generally accepted methods was spurred by the concept of co-ordination of insulation on transmission lines and station apparatus to realize inherent economic advantages (Philip Sporn[35] and others), because rational co-ordination required a fairly accurate knowledge of the impulse strength of the various types of apparatus involved. Because of insufficient confidence in the oscillograph methods, the first step was to compare an apparatus with a gap; for instance, for the first impulse test requirements for transformers in 1933[36] a gap spacing (standard rod gap) was specified and, thus, the test voltage was co-ordinated with the sparkover of the gap. This was expected to result in equivalent tests in the various testing plants. The oscillograph and dividers were used primarily as a wave shape control.

In the following years, co-operative work between five United States laboratories resulted in a committee report on the flashover characteristics of rod gaps and insulators,[37] where the curves obtained in various laboratories were within a spread of less than 5%, indicating a probable extreme variation from the average curve values given of ±8%. Two waves were used for the impulse tests, the 1x5- and the 1.5x40-microsecond waves. Humidity and air density corrections applicable to rod gaps and insulators were determined and published. As a consequence of the improved measurement techniques demonstrated, the AIEE Transformer Subcommittee changed the requirement for impulse testing of transformers from a gap basis to a voltage basis and adopted the 1.5x40 wave with prescribed tolerances.[38]

The use of a standard wave shape in the various laboratories was of great importance in arriving at consistent results. The Europeans and IEC adopted a 1x50 wave, however, with somewhat different definitions for the wave front as compared to the 1.5x40 American standard wave. Because of the variance in definitions and tolerances used for the two standard waves, they tend to overlap. At the IEC meeting of TC-42 in Munich, West Germany, in 1956 it was tentatively agreed to adopt a compromise wave of 1.2x50 microseconds and the IEC definitions for wave front and wave tail. It is

expected that this change will make insignificant differences in test results compared to previous practices.

Agreement between European laboratories has not been very goor on rod gaps, as reported by Prof. Berger.[39] The reasons for this are not entirely clear, because good agreement resulted on sphere gap comparisons. However, humidity corrections, which may be quite large for rod gaps, were not applied and an analysis has shown that this may be the primary reason for the greater variations, at least at positive polarity.

The various voltage dividers and oscillographs used in the five laboratories,[37] therefore, gave consistent results for the critical (50%) sparkover with 1.5x40 waves.

The introduction of steep-front tests for commercial tests for transformers and lightning arresters placed more stringent requirements on the voltage dividers. The resistance divider, therefore, was investigated and its response was determined for faster-rising wave fronts.[40] A shielded resistance divider was proposed to improve the response,[41] followed by many different suggestions for improving the measuring accuracy for impulses chopped at short times. In 1942, AIEE Standard no. 4 was revised to include measurements of standard impulse waves. At that time, no generally satisfactory methods were available to prove the accuracy of divider-oscillograph systems. In 1953, there was a further revision intended to standardize the value of the resistance used in a divider for measuring the voltage at a specified time. Such a procedure probably resulted in comparable tests being made at various test stations, but perhaps exceeded the specified error of $\pm 5\%$ in some cases.

Improved electronic pulse methods[42, 43] finally made it possible to investigate the divider system, including the high-voltage leads connecting the divider to the test specimen where the voltage wave is to be determined and the cable connecting the divider to the oscillograph and its terminations, with very small errors. Some investigators prefer to measure the frequency response of the divider systems.[44, 45] Inasmuch as these methods operate with very low voltage, methods employing higher voltages have been proposed consisting of establishing a standard volt–time curve for sphere gaps[46] and checking the divider system against such a curve. Investigations are still in progress to check these various methods, to obtain general agreement on the validity, and to establish numerical interrelations between the frequency response and pulse methods. Great progress has been made in this field largely as a result of the stimulation by N. Hylten-Cavallius as secretary of IEC TC-42 and the co-operation of various European and North American laboratories that have checked one or several of the proposed methods.

HIGH CURRENT SURGES

THE DEVELOPMENT of lightning arresters with nonlinear resistance valve elements required the production of high current surges and the measurement of wave shape and amplitude for design purposes.[47, 48] These generators utilize capacitors similar to the impulse voltage generator. However, they are arranged in parallel to obtain a high capacitance and to reduce the inductance of the impulse circuit. To obtain the highest current crests, the discharge path must be kept as short as possible (Fig. 4). Current crests up to 470 kiloamperes have been obtained with such generators. Some types of lightning arresters are required to withstand crest currents of 100 kiloamperes for a 5x10-microsecond wave. This is usually demonstrated on a prorated section of complete arrester.

The current is measured preferably by a coaxial tubular shunt[49] and cathode-ray oscillograph. For lower current crests, flat-strip shunts, consisting of a strip folded back on itself with a very thin sheet of insulation between the folded resistance metal, have been found well applicable.[50] However, the response time of these is generally greater than for the tubular shunts. Shunts made of parallel groups of twisted resistance wire also have been used with success.[47]

CATHODE-RAY OSCILLOGRAPH

THE CATHODE-RAY OSCILLOGRAPH undoubtedly has been the major tool that enabled the rapid advances in impulse testing. Originally, it was of the continuously evacuated type with the photographic material inside the vacuum chamber. Many workers still prefer this type, which now has become quite efficient because of much-improved vacuum techniques. A parallel line of development occurred with the sealed-tube oscillograph[51] with external photography of the trace by im-

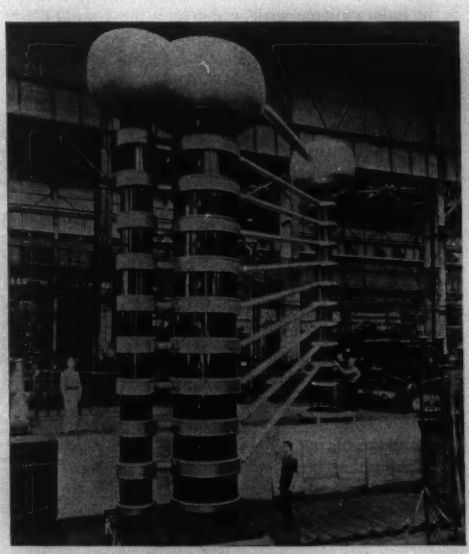

Fig. 5. GE high-voltage d-c constant-potential generator, 1,400 kv, 15 milliamperes. Side view showing complete assembly of main generator, voltage-divider stack, and X-ray-tube housing.

provements of the cathode-ray tubes, the screen materials, and the electronic circuitry associated with the oscillographs. The continuously evacuated oscillograph has a somewhat greater writing speed. However, the sealed-tube oscillograph has writing speeds sufficient for all tests now required by standards. Its major advantage is that it requires less skill and experience in its use and can readily be operated by laboratory technicians. Those who have worked with oscillographs from their inception will appreciate the magnificent progress that has been made. Thus, electronic progress has greatly assisted the power industry in its high-voltage measurement problems.

MISCELLANEOUS

THERE ARE A HOST of techniques developed largely for development testing. Of great importance has been the bridge technique developed by Prof. Schering[52] for testing of insulating materials and for determinations of errors and phase angles of instrument transformers. These techniques have been extended to potentials in excess of 500 kv by means of gas-filled capacitors at high pressures. Such bridges also have been used for measuring corona losses on experimental transmission lines.

Another tool that has been used extensively in recent years, but requires still further investigation, is the radio noise meter, both for apparatus testing and determining radio influence voltages from transmission lines. There is still much discussion about the meters. European practice favors the CISPR rules[53], American practice favors NEMA rules[54] which are now being revised[55] to include a meter with a shorter time constant.[56, 57] The NEMA rules include methods of measuring conducted radio noise, but CISPR rules do not. A comparison between various meters has been made by CIGRE Study Committee no. 9.[58]

There is also considerable disagreement about the preferred quantity to measure—peak, quasipeak, or mean square value of the disturbing signals. From theoretical considerations[59] the mean square value is desirable. However, meters have not been available to measure this quantity until recently.[60] There probably will be rapid developments in this field during the next few years, because of its importance in apparatus design and the design of transmission lines.

Development of high direct voltages has occurred primarily for the purpose of high-voltage X-ray and nuclear techniques. Fig. 5 shows a 1,400-kv d-c generator[61] for X-ray studies at the National Bureau of Standards' High Voltage Laboratory. This is a cascaded arrangement of ten 140-kv rectifier units. There are many other vacuum tube circuits that have been developed for generating high direct voltages. By using a moving belt to transport charges from a low-voltage imput to a high-voltage collector, Van de Graaff, Trump, and their associates have built linear accelerators for X-ray and nuclear studies up to 12 million volts.[62] By the use of compressed-gas insulation they have succeeded in keeping these electrostatic generators to very small sizes.

In the power field, the use of d-c testing has been largely for cable testing, both for acceptance tests and preventive maintenance in the field at moderate voltages. With the advent of d-c transmission, particularly in the USSR and Sweden, it is to be expected that testing at higher d-c voltages will increase and suitable test methods will be refined. American studies have indicated that the use of d-c transmission in the United States may not be economical.[64, 65]

CONCLUSIONS

IT IS BELIEVED that this review shows that testing and measuring techniques in the high-voltage field have kept step with the requirements of the power industries and have greatly aided in the successful operation of large transmission systems.

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Developments in Distribution Apparatus and Systems

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ALTHOUGH the distribution field may not seem as spectacular as others, it represents approximately half the total power system investment. It is in this area that the ultimate quality of service is determined. Future opportunities for improving the quality and minimizing the cost of electrical service are believed to be greatest in the distribution field.

SUBTRANSMISSION

SUBTRANSMISSION SYSTEMS were at lower voltages 25 years ago, inasmuch as generation was usually close to the load being served. In contrast, today's new generation is usually remote from load areas and feeds into high-voltage interconnected transmission systems which deliver power to bulk substations. Here, it is transformed to the subtransmission voltage.

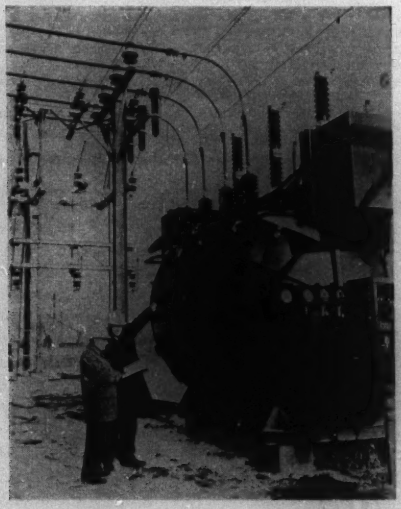

Fig. 1. Gas-filled power transformer, 66-12 kv, 10,000 kva.

As systems expand with higher-voltage transmission networks superimposed, the next lower system voltage, formerly transmission, gradually resorts to subtransmission. In this way, many former 69-kv transmission systems have already become subtransmission; this is now happening to many 115- and 138-kv systems and this trend is certain to continue. In fact, direct transformation from 230-kv to 12-kv residential distribution is being made. Therefore, it can be said that subtransmission voltages in use today cover the range of 11 kv to 230 kv.

One of the traditional ways of minimizing system investment is to serve new load through one less transformation than in the past. The voltage that is bypassed is usually the lower of two subtransmission voltages, often in conjunction with the introduction of a higher distribution voltage. Examples of how this is happening would be a former 69-13-4 kv system which is now picking up new load and expanding at 69-13 kv, or a former 230-115-69-12 kv system which is picking up new load at 230-115-12 kv.

The common transformer bank fed by subtransmission systems 25 years ago was three or four single-phase self-cooled units of full BIL (basic impulse insulation level). Today, 3-phase transformers are almost universally accepted, and forced cooling is used for firm continuous ratings. Reduced insulation of one or more classes is being used at voltages of 115 kv and higher, the result of impulse testing that was started in the early 1930's, improvements in lightning arrester performance, and increased knowledge of abnormal voltages.

Future transformers are expected to include continued improvements in materials and designs to reduce size, weights, and insulation levels further. Hot-rolled silicon core steel has been replaced by cold-rolled grain-oriented steel with improved magnetic characteristics in one direction. The next steel development may be improved properties in two directions of the strip surface to give further improvements in loss and audible sound performance. Pioneering work now being done is expected to result in replacement of oil by gaseous dielectric and cooling mediums (Fig. 1).

Mobile substations first introduced in the 1930's have done much to permit reductions in spare transformer capacity and permit widespread acceptance of 3-phase transformers in industrial and distribution substations. Reductions in weight per kva have permitted higher-rated units (Fig. 2) which also have found much usage during routine construction and maintenance. Use of mobile transformer reserve is now expanding into the

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Fig. 2. Typical mobile substation, rated 12,000 kva, type FOA, 69-13.8 kv, with primary and secondary switchgear.

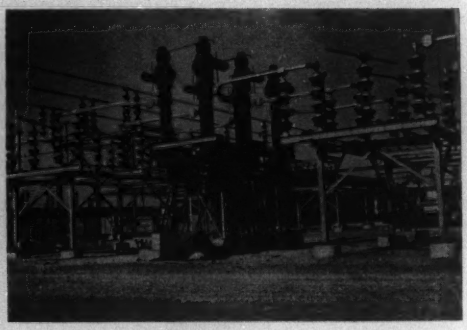

Fig. 3. 138-kv air blast breaker with interrupting unit in high-pressure air storage tank on each column.

larger subtransmission substations as illustrated by a 230-kv 40-mva single-phase highway type placed in service this year.

Subtransmission circuit breakers have become more reliable, with shorter interrupting times, and extensive use is made of automatic reclosing. Oilless breakers are finding increasing use at transmission voltages and, in the future, are expected to be used at subtransmission voltages as well (Fig. 3).

The most significant developments in relaying have been toward high-speed operation. One-cycle operating time is available for practically all types of faults by means of pilot, distance, and differential relays utilizing low-inertia cylinder elements in place of the older induction disk. The present trend is from electromechanical means to the use of electronic technology and semiconductors to detect faults. By 1984, such static relays will be available for all types of protection. It is even conceivable that individual relays might be replaced by a centrally located device which would analyze quantities from the system and determine what breakers should be tripped.

METROPOLITAN DISTRIBUTION

In 1934, the underground 208-volt secondary a-c network system, rather than d-c systems, was absorbing load growth in most metropolitan areas. Today, almost all large cities have secondary networks. Remaining d-c systems are continually shrinking. Present secondary network peak load is in excess of 6 million kva. Each year several smaller towns start new secondary networks in the business sections.

Although 2.4- to 4.8-kv potentials initially were used to feed some secondary networks, congestion and economics have resulted in prevalent use today of voltages in the 11- to 14-kv range. Some networks are fed at 23, 27, 34.5, and even 69 kv. Future increased usage of these voltages is expected as justified by higher load density and larger average size of network transformers.

Improved materials and designs have permitted continual decreases in the dimensions of network transformers (Fig. 4). In most cases, these reductions permit substitution of a larger rating transformer in existing vaults originally designed for a lower rating; for example, replacing a 500-kva unit with a 750- or even 1,000-kva unit.

Nonlead-covered cable is now almost exclusively used for secondary cable additions and, to an increasing extent, for primary cables. This has been made possible by the introduction of new synthetic insulations such as Buna S and Butyl with neoprene jacket to give continually improved moisture, oil, flame, and corona resistance.

Until World War II, many networks were fed directly from local generating station busses. Since then, much of the network growth has been served from substations established in the metropolitan load areas to receive power from remote generation via subtransmission usually in the 69- to 138-kv range. These substations are located on expensive real estate in congested areas, and first utilized the same switchgear of the oil or air-blast cubicle-type construction used in the bussed generating stations which they relieved. Soon

Fig. 4. The height of today's 750-kva network transformer has been reduced more than 25% as compared to a 1934 500-kva unit or the 1954 750-kva unit shown.

Fig. 5. Typical installation of 13.8-kv, 750-mva metal-clad switchgear in metropolitan substation.

economy and compactness led to the use of metal-clad switchgear with removable 13.8-kv 500-mva magnetic air-type circuit breakers. Increasing load densities and the economy of larger substations brought about the increase to 750-mva interrupting rating in 1955 (Fig. 5) and the first 1,000-mva installations are being made this year.

The second change since the mid-1940's has been the numerous concentrated loads as large as 6,000 to 15,000 kva per building being created by the modernization and air conditioning of existing buildings as well as by new construction. Multiple transformer installations are required to serve these loads and the voltage of 265/460 Y has been found to permit savings inside the building in addition to allowing larger network transformers to be used; for example, 2,000 kva at 460 volts as compared to 1,000 kva at 208 volts. Higher network protector and transformer ratings will be introduced as these building loads become larger and the supply voltages increase above 13.8 kv.

RESIDENTIAL DISTRIBUTION

CHANGES in residential distribution systems are influenced by the increase in residential usage of electricity, which is traditionally at a faster rate than other type loads. In 1934, the average yearly usage per customer was 629 kwhr. This increased to 3,174 kwhr in 1957, and has been forecast as approximately 16,000 kwhr in 1984. In 1934, electricity was used mostly for lighting. The electric refrigerator had only achieved 33% saturation in wired homes, even though available since 1912. Electric refrigerator saturation in wired homes in 1958 reached 98%. Much of the increased usage is due to new devices which provide added convenience, comfort, and enjoyment; for example, television, which grew from 4% saturation in 1948 to 89% saturation in 1958. Heating and cooling are expected to have the greatest effect on future loads.

Twenty-five years ago, some primary distribution was at 2,400 volts, but most companies had converted to 4,160 volts Y or 4,800 volts delta. Only a few companies, particularly in rural and semirural areas, were making use of distribution voltages in the 11–13-kv range. Large distribution substations, usually indoor and attended, were common practice. There was, however, controversy at that time on the advisability and economics of expanding with fewer large substations vs the use of smaller automatic substations, such as the factory-assembled unit type then being introduced. Step-by-step expansion with new bus-regulated substations has become more common (Fig. 6). Average substation size is increasing rapidly as a result of higher voltages, heavier loads, and as right-of-way or site procurement becomes more difficult.

Today's distribution systems make extensive use of higher voltages. Of the distribution transformers now being supplied, approximately two thirds of the number, and one half of the kva are with primary voltage above 5 kv. The most commonly used voltages are 7,200/12,470 Y and 7,620/13,200 Y. Some 4-kv systems have been eliminated by conversion to higher voltage and many are being limited to present demand or geographical boundaries with the majority of load growth being picked up by higher voltages. Within the past few years quite a number of systems in the 21–25-kv range have been introduced, sometimes by wyeing up 12-kv delta systems or by utilizing a voltage which had previously been established as subtransmission. More recently in very limited use, several companies are studying 34.5-kv primary distribution. Voltages in the 11–13-kv range are expected to predominate in the future with increasing use of the 21–25-kv range and some usage of 34.5 kv.

Secondary voltage has remained predominantly 120/240 single-phase, with use of 3-phase now being restricted mostly to those cases of air conditioning or heat pumps with motors larger than 5 to 7½ hp. Consideration is now being given to the use of residential

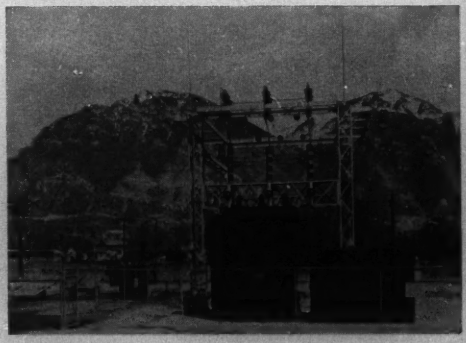

Fig. 6. Modern unit substation with incoming line structure, load tap changing transformer and outdoor metal-clad switchgear.

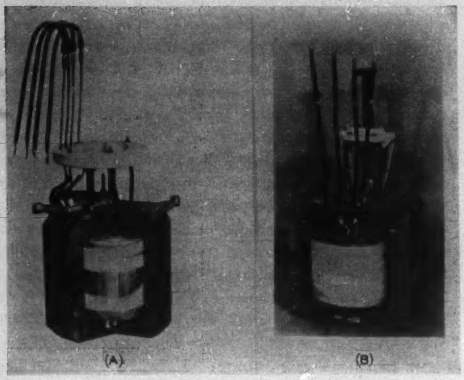

Fig. 7. (A) 15-kva, 1934 distribution transformer with core of hot-rolled steel punchings. (B) 1959 design with wound core of cold-rolled steel and Formex*-insulated windings.

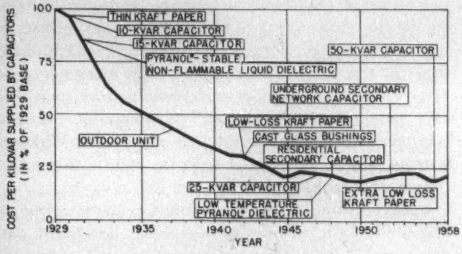

Fig. 8. Capacitor developments.

voltages of 240/480 volts single-phase in new high-demand areas with only fixed appliances using 240 volts to ground. For the foreseeable future, this will require the use of autotransformers to serve incandescent lighting and portable appliances at 120 volts. This is to avoid the inconvenience and added cost of the industry having both 120- and 240-volt lamps and portable appliances. Some, however, have the hope that future developments in light sources and portable appliances may be more suitable for use on 240 volts to eliminate the need for the autotransformer. Higher-voltage installations to gain experience are expected in the near future.

Underground distribution in residential areas has been increasing, but slowly because of added cost as compared to the traditional overhead system. Usage to date has been mostly in housing developments where the tract developer assumes part or all of the added cost. Future usage is expected to increase, particularly as more consumers are willing to pay for it, by direct burial of synthetic rubber-type cables and by joint burial with telephone facilities.

The heart of the distribution system, the distribution transformer, and the watt-hour meter have become the most highly standardized and mass-produced apparatus used by the utilities. Compared with those built 25 years ago, today's distribution transformers, on the average, have 24% less core loss, 6.5% less full-load loss, 30% lower voltage regulation at 0.8 power factor, and 37% less weight (Fig. 7).

Watt-hour meters have been improved by standardization of outdoor socket mounting, extended load range, use of more stable alnico damping magnets, and by new bearing materials and designs that have been introduced. Statistical sampling for acceptance as well as for periodic tests is expected to increase and should make possible future hermetically sealed meters with no adjustments, since the emphasis will be on long-time stability. Future developments in data transmission and processing may make an automatic meter reading and billing system economical.

Supplying reactive vars near the load rather than transmitting them from generating stations or synchronous condensers has become the rule rather than the exception. This has been made economical by individual Pyranol*-filled outdoor capacitors with continual engineering and manufacturing improvements, as illustrated by Fig. 8. Increasing use is also being made of switched capacitors for voltage control. Because of the individual case-type construction adopted, the same basic capacitors can be used on distribution circuits or stacked for use in higher voltage shunt or series applications. As system power factors approach unity, new types of controls may be expected. For example, recently introduced remote automatic control via carrier current will permit flexible and accurate scheduling of kvar generation. Increased usage of series capacitors is expected to improve load division in high-voltage systems, and to reduce distribution voltage drop and flicker.

Higher system power factor, distribution voltages, and load densities have permitted the use of larger

Fig. 9. Single-phase 2,400-volt step-voltage regulators. (A) 1936 design, 25 kva, with 2½ % steps; (B) 1959 design, 167 kva, with ⅝ % steps.

*Registered trade mark, General Electric Company.

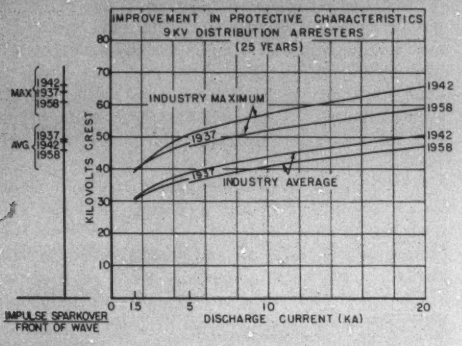

Fig. 10. Periodic improvements in distribution-type lightning arresters.

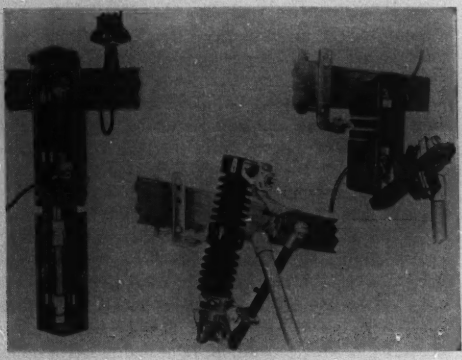

Fig. 11. Early fuse cutout with wet process porcelain housing, corresponding 100-ampere 5.2-kv rating today and *(lower center)* 1959 open-type typical of higher voltage ratings.

voltage regulators. Added emphasis has been on the lower cost associated with step-type construction (Fig. 9) with reductions in step size and reduced maintenance, due particularly to increased contact-tip life.

Increasing dependence on electric service, along with higher distribution voltages, circuit loadings, and fault currents, have necessitated careful attention to the maintenance and improvement of service continuity. This has been reflected both in line construction, where larger conductors or aerial cable is used, and in protective devices. Distribution lightning arresters have been reduced approximately 40% in length, along with improvements in protective levels (Fig. 10), discharge capability, sealing techniques, and reliability.

Improvements in fuse cutouts (Fig. 11) include higher continuous and interrupting ratings, introduction of load-breaking ability, and fuse links with improved accuracy and time–current characteristics designed for co-ordination with relays and reclosers. The inability of a fuse to distinguish between temporary and permanent faults led to the use of fuses in conjunction with instantaneous relays and automatic reclosing breakers in the 1930's to remove transient faults and restore service to the entire feeder. Subsequent distribution breakers have achieved faster interrupting times of 8 and presently 5 or 2 cycles to improve co-ordination and to minimize wire burndown.

Additional sectionalizing of longer high-voltage feeders was required and the first automatic circuit recloser with self-contained tripping and automatic reclosing mechanisms was introduced in 1934 (Fig. 12). Usage of reclosers co-ordinated with fuses has increased for distribution circuit sectionalizing, for sectionalizing lower voltage subtransmission lines, and as feeder protection in small to moderate size substations. Both single- and 3-phase reclosers are now built with ratings up to 560 amperes continuous at 14.4 kv and 400 amperes continuous at 46 kv.

INDUSTRIAL DISTRIBUTION

In 1934, the typical industrial power distribution system was characterized by a single, large substation at the service entrance, stepping from primary voltage to utilization voltage. Long, heavy secondary feeders to the loads in the plant were required. The efficiency, cost, and voltage regulation of such systems were poor and they were difficult to expand. A prominent electrical engineer said facetiously that, in constructing old-style systems, it was common practice to "buy a carload of copper and build a plant around it."

In the ensuing 25 years a revolution has occurred in this field. Basic principles have been developed and documented in AIEE publication no. 952, "Electric Power Distribution for Industrial Plants." Industrial use of electric power accounts for about half of all electric energy consumed in the United States. In 1984, the heavy manufacturing and mining usage is forecast at 1,705 billion kwhr per year, or 5.1 times present use. This is expected to permit 2.4 times as much output of goods with only one third more workers. Kilowatt-hours

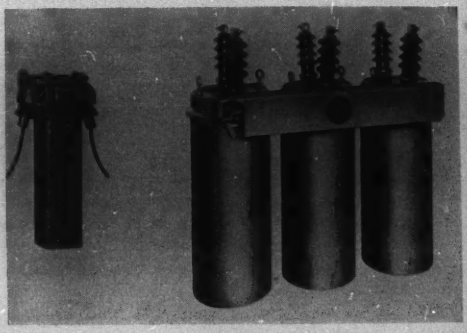

Fig. 12. First oil circuit recloser rated 7.5 kv, 50 amperes and larger unit typical of 1959.

per worker per year are expected to advance from 26,600 at present to 101,500 in 1984.

The capacities of many industrial operations rival those of medium-sized cities. Typically, primary power is purchased from the utility and distributed at medium voltage to unit substations at load-center locations throughout the plant. Such load-center distribution systems can be expanded to as many as 100 or more unit substations, and can supply plants larger than any now planned or in existence.

The main bulk power substation for an industrial plant closely resembles those previously described in connection with subtransmission and residential distribution systems. Progressing to the in-plant area, the main primary switchgear forms the system nucleus to which all power is brought and from which all power radiates. Fig. 13 illustrates the progress that has been made in this field, including air instead of oil breakers, flame-retardant nontracking insulations, and safety and maintenance flexibility permitted by easily removable devices such as breakers, relays, and potential transformers.

A significant development in plant feeder construction since 1934 is the interlocked armor cable system (Fig. 14). The system is lower in cost than conduit or duct construction. It is accessible for inspection and repair, and can be rerouted to accommodate production setup changes. The armor provides mechanical protection but is flexible enough to allow long lengths of cable to be pulled into place with numerous bends.

The key to improved industrial power system design has proved to be the secondary unit substation or distribution center (Fig. 15). Intensive development of indoor transformers has provided three types which can be installed in load-center locations without vaults; the askarel transformer, the open ventilated dry type, and the sealed dry type.

Interrupting capacity requirements in low-voltage systems have been recognized and accepted in industry. To meet these requirements, drawout metal-enclosed switchgar has been developed with magnetic low-voltage power circuit breakers of improved performance and characteristics.

In 1934, low-voltage systems in the 240-volt ungrounded class were extensively employed. At present, 80% of all new industrial low-voltage systems involve 480 volts for area coverage, and two thirds of these are of the grounded-neutral type.

The industrial utilization of d-c power is increasing at about the same rate as that of alternating current. Electrolytic processes are almost universally handled with direct current, and many drives can best be handled with d-c motors because speed can be varied smoothly from zero to maximum with good torque efficiency.

In new installations, the rectifier has almost completely replaced rotating machinery for constant-voltage d-c power supply. At present, the field of power conversion is rapidly changing as a result of recurring innovations. Currently, silicon has emerged as the pre-

Fig. 13. Metal-clad switchgear with 4.16-kv air magnetic circuit breakers beside old open-type switchgear which it replaced.

Fig. 14. Interlocked armor cable installed on accessible racks.

Fig. 15. Secondary unit substation with sealed dry type transformer and drawout switchgear.

Fig. 16. Silicon rectifier installation at Hooker Chemical Corp., Niagara Falls, N.Y., rated 12,000 amperes output at 360 volts d-c.

Fig. 17. Adjustable speed d-c drive with magnetic amplifier and silicon rectifier power unit.

ferred monocrystalline high-current semiconductor in the medium d-c voltage field (Fig. 16).

Magnetic amplifiers using silicon rectifiers to supply d-c shunt motor armature and field circuits directly are employed on drives up to 200 hp with adjustable speed over a 10-to-1 range (Fig. 17). Further development of the "controlled" semiconductor rectifier, which provides characteristics similar to those of the ignitron or thyratron, will bring future simplification.

Traditional low-voltage busway in 1934 was designed with widely spaced copper bars, resulting in high reactance. Originally developed for applications where frequent changes in production setup are experienced, usage of plug-in busway (Fig. 18) has been extended materially in industry and commercial buildings because of marked design and installation improvements. At present, Butyl-insulated aluminum bars permit closer spacing and interlacing of bars to provide lower reactance and lower voltage drop.

The motor itself typifies progress that has been made (Fig. 19). Improvements in enclosures provide considerable protection against entry of foreign materials. Lower starting currents, higher efficiencies, and lower noise levels have been achieved with reductions of 50% in weight and 33% in volume. Insulation failure has been reduced by tough film-covered wires which have largely replaced cotton for random-wound motors. Motors of the future will have advanced insulation systems operating at higher temperature and providing more complete sealing and moisture protection.

Other developments have been made in molded-case circuit breakers, compact high-performance starters, and group control. These are illustrated together in a motor control center (Fig. 20). Molded-case circuit breakers are now widely applied in industry for branch-circuit protection. Twenty-five years ago most magnetic motor starters were large, clapper-type devices. Since then, compact high-performance types have progressed to the vertical, and more recently to horizontal motion designs. The motor control center permits grouping motor starters at one location.

In a very large industrial operation, as many as 50,000 safety switches may be installed on the system. A quarter of a century ago these were merely enclosed knife switches. Under continuous development, these have progressed to precision switching devices with definite ratings and, when equipped with current-limiting fuses, permit application on high-capacity circuits.

CONCLUSION

Apparatus improvements have been a combination of new engineering concepts and designs, the introduction of new materials, and more efficient use of materials, thus minimizing cost and resulting in more reliable, efficient, and smaller equipment. Examples of broad significance are the improvements in magnetic properties of steel, increased usage of aluminum, and

Fig. 18. Installation of 480-volt feeder busway, with removable covers for plug-in outlets.

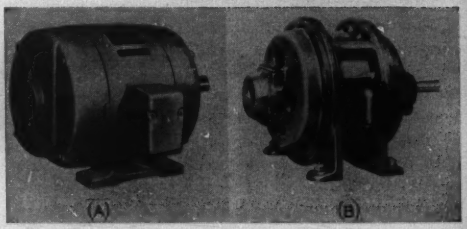

Fig. 19. Comparison of (A) modern and (B) old-style motors.

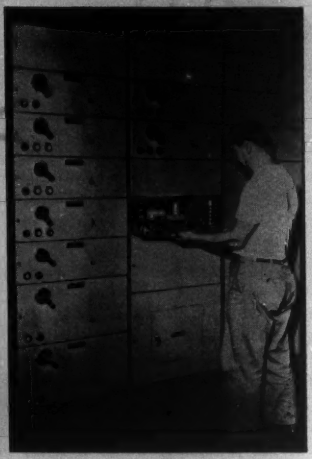

Fig. 20. Motor control center with plug-in combination starters incorporating molded case circuit breaker, contactor, and overload relays.

decreasing dependence upon oil as an insulating and interrupting medium. Much apparatus was originally based on the properties of oil, paper, and air at atmospheric pressure, whereas we now see increasing usage of compressed air, vacuum, synthetic fluids or solids, and chemically produced gases. It seems certain that improved materials of the future will come from the laboratory rather than from nature.

In a similar manner, new designs and materials are more thoroughly proved and tested in laboratories today than has been possible in the past. This is evidenced by the new and expanded test facilities continually being made available. Examples are the higher capacity now available for switchgear testing, and new sound laboratories for testing transformers, motors, and ballasts.

Further benefit to both user and producer through standardization is anticipated. These benefits become more important with industry growth and volume.

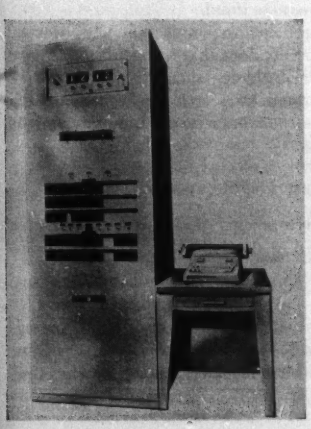

Fig. 21. Supervisory equipment master station incorporating digital data receiving and logging system.

Analog computers, such as network analyzers, have long been used by the electrical industry. Today, digital computers and data-processing equipment are finding increasing use in the solution of both system engineering and equipment design problems. These new tools will be particularly useful in the distribution area where such a large number of variables and repetitive operations are involved.

System operation may be further automated with automatic programming and data logging operated over supervisory equipment. Initial applications of this principle (Fig. 21) have been favorable.

Widespread application of static control and switching is expected. With static control (Fig. 22), conventional circuit-making and breaking devices are replaced by devices which perform the decision-making function on a logical basis using, to some extent, the same

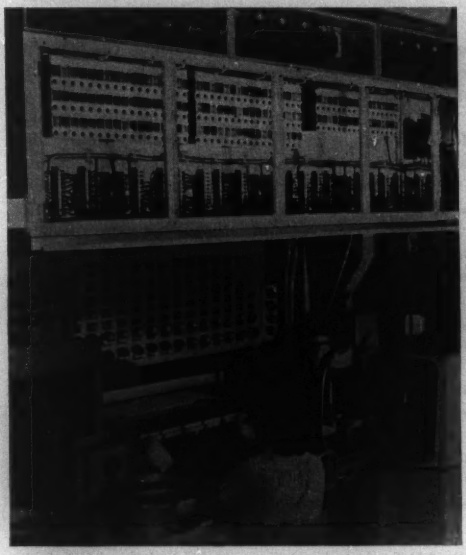

Fig. 22. Static switching control panel with logic elements in upper half of picture controlling spark plug assembly machine.

methods employed in the human reasoning process. Static elements are fast, immune to most environment conditions, reliable, and long-lived, because there are no moving parts.

In 1934, one might have thought that this field was relatively mature in an engineering sense. Progress since then indicates that such an appraisal would have been erroneous. Similarly, at present there is every reason to believe that the 25 years ahead will open new engineering horizons in the continued search for improved service quality and more economical distribution.

Insulated Electric Power Cables

HERMAN HALPERIN

FELLOW AIEE

IN THE PAST 25 YEARS many diverse and exciting developments have appeared in insulated electric power cables of all voltages and in all matters relating to them. The importance of the entire field has greatly expanded mainly as a result of (1) the rapid growth in the use of electric power, (2) the increasing use of underground instead of overhead lines, and (3) the sharp rise in costs of cable installations.

The developments have applied to all insulated conductors whether in the home, in the factory, in the utility plant, on board ship, etc. Some major advances and changes are as follows:

1. Development of many new synthetics to replace natural rubber or as new compounds in the manufacture of (a) insulation for lower-voltage wires and cables or (b) protective jackets.
2. Expansion in types and uses of metallic coverings for lower-voltage cables, and development of lead alloys and aluminum for sheaths for cables of all voltages.
3. Introduction of segmental construction to reduce skin effect for very large conductors.
4. Many new designs of impregnated-paper-insulated high-voltage cables. (Use of pipe-type has grown particularly in the United States.)
5. New designs of joints and terminations for all voltages, and development of new insulating materials for this application.
6. Advances in design of conduits, manholes, pipes, trays and supports in air, etc., to increase cable life and reduce costs.
7. Increased utilization by use of higher permissible temperatures for normal operation for practically all types of insulation and by introduction of still higher temperatures for emergency operation.

The growing importance of cables was recognized by the AIEE when, in 1947, it established the AIEE Insulated Conductors Committee, which with its 14 subcommittees has been covering the field very actively. Previously only a small part of the work had been handled by a subcommittee of another committee.

The rapid increase in the use of higher-voltage underground cables has been due to various causes such as: (1) increase in housing, especially in areas adjacent to larger cities, which has reduced the feasible locations for overhead lines; (2) problems of some utilities in finding room for lower-voltage underground lines in congested areas; and (3) economic attractiveness of transmitting large blocks of power to transmission substations and then distributing from them with relatively short subtransmission lines.

In the United States, the over-all effect has been the increase in mileage of underground lines operating at 69 kv or more from about 220 circuit-miles in 1933 to about 1,750 miles in 1958. In 1933, 80 per cent of the cable was operating at 69 kv, and most of the remainder at 138 kv, at that time the highest cable voltage in the world. At present, a large majority of the lines are operating at 110 to 138 kv, with a little up to 230 kv.

In Canada, the corresponding change has been from 4 to 190 miles, with some lines at present in ducts operating at 230 kv and some in a tunnel at 301 kv. It may also be noted that in Sweden short pieces of cable are operating at 400 to 425 kv in ventilated vertical shafts.

The importance of the problems of insulated conductors is illustrated by the following: for a given operating voltage and load, the installed cost of the underground facilities is from 2 or 3 times to as much as 16 times that of overhead facilities; and reliability in service is particularly important for the underground facilities, because a failure causes a line outage lasting from 1 or 2 days up to 10 days or longer, while a forced outage of an overhead line may last from only a few cycles up to 1 or 2 days.

A characteristic peculiar to installations of insulated conductors as compared with most other facilities is that their service performance is dependent to a large degree on factors external to the factory-made product (the insulated cable): the accessories employed, the field conditions and workmanship during installation, and conditions and maintenance during operation. For an installed motor, transformer, or generator, the equipment is so self-contained that it is practically fabricated in final operation condition at the factory. Operating troubles of circuits of insulated conductors nowadays stem mostly from causes not associated with the cable and accessories as manufactured.

The range of problems in connection with electric power cables is so tremendous that the solutions require help from the fields of physics, chemistry, mathematics, and mechanics. Also much research has been conducted by cable and accessory manufacturers, by users, and by research institutions.

Past Developments

OUTSTANDING developments of the past quarter of a century are outlined in the following general sections.

CONDUCTORS

ONE OUTSTANDING development has been the segmental construction for extra-large conductors, as illustrated in Figs. 1 and 2. The skin effect approaches that

Mr. Halperin is with the Commonwealth Edison Co., Chicago, Ill.

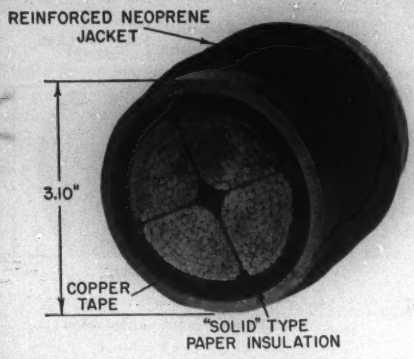

Fig. 1. A 4,000 MCM segmental conductor in 20-kv cable.

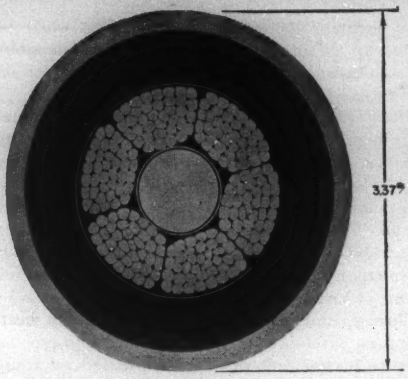

Fig. 2. A 2,250 MCM hollow-core segmental conductor in 138-kv oil-filled cbale.

of the individual segments with the result that either very large conductors may be effectively used or the conductor size for a given current may be reduced by 10 to 30 per cent.

Another trend has resulted in changes in the shape of the strands from the usual round cross section. One procedure is to compact them, more or less (Figs. 1 and 2). Compacting is applied also to sector-shaped conductors in multiconductor cable and to round conductors. This practice results in a smaller cable and reduced cost. The compacting work-hardens the copper, thereby making it more stiff and springy. In some cables (Figs. 3 and 4), the individual strands are preshaped to produce a practically solid conductor structure and a smooth surface.

In recent years, aluminum has been found, in some cases, to have advantages over copper for service drop wires and in wiring installations in factories, and has been used for a few underground lines. Such uses have been accentuated in recent periods when the price of copper was relatively high compared to that of aluminum. With this increased interest in aluminum, special work has been done to obtain permanently satisfactory connections.

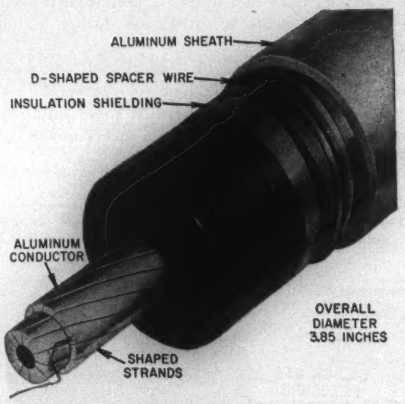

Fig. 3. A 301-kv medium-pressure oil-filled cable using aluminum. (Made and installed in Canada.)

SHEATHS AND COVERINGS

Lead and Lead Alloys. Lead sheaths used to protect cable insulation, especially underground, have often in the past contained impurities or a high degree of eccentricity in thickness which caused sheath openings and service failures. These deficiencies were successfully overcome by various changes in the design and operation of lead presses and auxiliaries.

In the case of the larger underground cables, the small daily flexing of the sheaths in the manholes incidental to the cable movement back and forth in the duct with daily load changes had caused premature cracking of the sheaths. The developments of lead alloys containing a little arsenic and tin with or without some tellurium has produced sheaths having three to five times the life of ordinary lead sheaths. This improve-

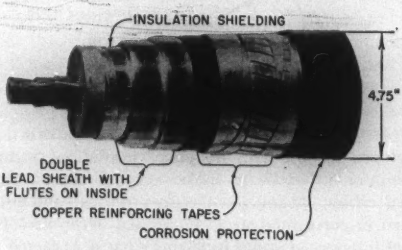

Fig. 4. A 380-kv high-pressure oil-filled cable operating at 410 kv in vertical shaft. (Made and installed in Sweden.) *Note:* Recently a cable of similar design but rated at 500 kv and operating at 420 kv was made in France and installed in a shaft in Sweden; cooled by circulating oil.

ment facilitates the use of higher loadings where permitted by the insulation, and permits tensile stresses (for cables with internal pressure) 40 to 60 per cent above those for ordinary lead sheaths.

Aluminum Sheaths. Aluminum, because of its relatively high strength and light weight, has been introduced as a sheath material for various applications, notably as follows: (1) cables installed in air in industrial plants and in stations and substations, especially abroad; (2) aerial cables where the lighter weight is an advantage; and (3) oil-filled self-contained cables where the internal pressures would have required special reinforcing of lead sheath.

Three general methods of applying aluminum sheaths have been developed: (1) cable is pulled into pipe and the pipe is swaged down; (2) a strip is formed around the cable and seam welded; and (3) hot aluminum is extruded directly onto the cable. The latter scheme imposes no limitation on the length of cable which can be made. A new German press for this purpose was recently installed in the United States. Where a bending radius smaller than that normally permitted is desired, the aluminum sheath is corrugated during manufacture.

Aluminum-sheathed cable installed underground, whether buried or in a duct, requires a protective jacket to prevent corrosion. Lead-sheathed cable installed in conduit usually does not require a jacket unless corrosive conditions exist.

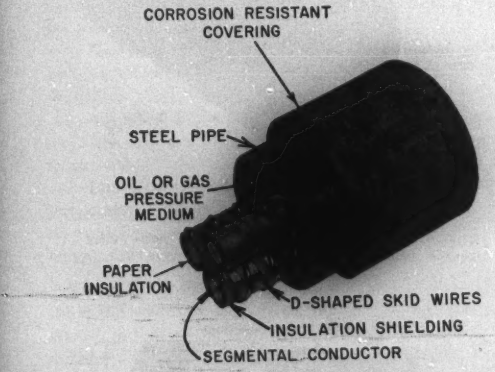

Fig. 5. High-pressure pipe-type cable.

Other Metallic Coverings. Other special constructions developed for use over nonpaper insulations include aluminum or steel-wire basket-weave braid on shipboard cables; drawn down copper tubing; and interlocked or corrugated steel, aluminum, or bronze. The use of interlocked armor in factories has skyrocketed.

In high-voltage, pipe-type lines, the steel pipe serves in effect as the impermeable sheath because the cables usually have no substantial protective covering over the insulation (Fig. 5). Corrosion protection of the buried pipe generally consists of a sand-asbestos-asphalt-based

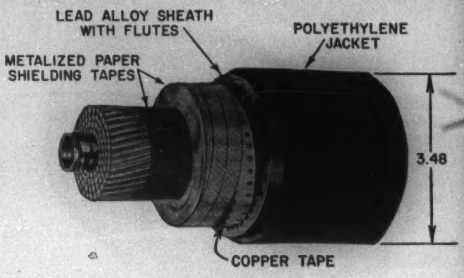

Fig. 6. A 230-kv low-pressure oil-filled cable.

compound. For self-contained high-pressure cables, the lead sheath, when used, requires metallic reinforcing tapes which have been developed to withstand internal pressures of about 200 pounds per square inch (psi).

Nonmetallic Coverings. Several coverings have been developed for protection of either rubber and synthetic insulations or of metallic coverings. Neoprene has been used extensively instead of cotton for coverings over rubber or synthetic insulation. A composite vulcanized structure consisting of neoprene and cotton tapes has been used widely as a protection for lead sheaths for cables buried directly in the ground or in ducts with corrosive conditions.

Another jacket material which has been used to some extent in this country and considerably in Europe is plasticized polyvinylchloride (PVC), a thermoplastic synthetic highly resistant to many chemicals. It can be extruded at high speed and needs no vulcanization.

A third new jacket material is polyethylene, which is also a thermoplastic (Fig. 6). In the initial use, clear polyethylene cracked when exposed to the effects of the sun's rays. Also in early applications, some jackets employing low molecular-weight material split open because of environmental effects of oil, sodium hydroxide, or other substances encountered in underground waters with the jacket under strain. The introduction of carbon black into the polyethylene and the use of higher molecular weight polyethylenes have solved the former difficulty, while marked improvement has been made regarding the latter.

Both PVC and polyethylene have been used as jackets over other insulations and as coverings over lead or aluminum sheaths, but to a lesser extent in this country than neoprene; however, use of polyethylene jackets is increasing relatively fast.

LOW-VOLTAGE CABLES

LOW-VOLTAGE CABLES are defined as those operating up to 7.5 kv, or 15 kv, or 35 kv, depending primarily upon the type of cable, characteristics of the insulation, and accounting practices. The lower voltage cables are used in a great variety of conditions of installation and operation. The electrical stresses and losses in the dielectrics are from negligible to moderate.

Solid-Type Paper-Insulated. This type of cable continues to be used extensively, but its use in the 120- to 15,000-volt range has decreased percentagewise somewhat in inverse proportion to the operating voltages. Improvements have been made in the quality of new cable insulation, as indicated in power-factor tests of the individual tapes which usually show uniformly low values (Fig. 7). Tests on earlier cables frequently showed high upturns in power factors, particularly for the inner and outer tapes, indicating impurities. Table I shows the decreases in over-all power factors which have been achieved.

Table I. Typical Power Factors of New Paper-Insulated Cable in Per Cent

	at 25 C		at 85 C	
Type of Cable	1933	1958	1933	1958
Solid	0.55	0.35	1.8	0.5
Low-pressure oil-filled	0.4	0.3	0.4	0.3

The use of special shielding tapes over each conductor has been introduced for 10 kv and higher voltages. These consist of either aluminum-coated paper tapes or carbon-black paper tapes which in effect make the conductor surface a smoother electrode to decrease the maximum stresses. Such tapes act also as a barrier to the ingress of deterioration products because of possible interaction of copper and compound. Conductor shielding is used also for other cable types, as indicated in Figs. 6 and 8.

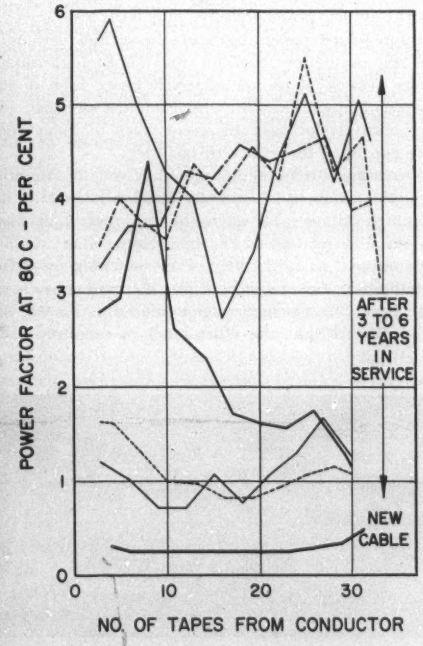

Fig. 7. Radial power factor tests of insulation in 12-kv 3-conductor shielded cable.

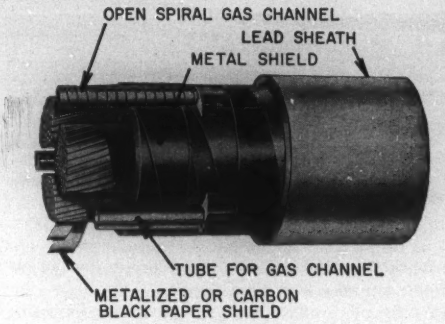

Fig. 8. Low-pressure gas-filled cable.

For 10-kv and higher voltage 3-conductor cables, the shielded type of cable (shielding tapes over the insulation of each conductor) has practically replaced the belted type.

Accelerated life tests and operating experiences have demonstrated increases in unit dielectric strength and in allowable operating temperatures for cable with conductor and insulation shielding. These and other improvements have permitted reductions in insulation thicknesses, as indicated in Table II.

Table II. Standard Thicknesses of Impregnated Paper Insulation for Two Types of One-Conductor Cable

Type of Cable	Rated (Kv)	Average Thickness—Mils 1934-38	Average Thickness—Mils 1951-58	Decrease (Per Cent)
Solid	15	203	175	14
Solid	35	375	345	8
Solid	69	688	650	6
Oil-filled	69	350	285	19
Oil-filled	138	625	505	19
Oil-filled	230	925	835	10

"Rubber"-Insulated. A phenomenal development of synthetics has occurred in the field of rubber-insulated wires and cables. Twenty-five years ago, essentially only rubber and other materials in the natural state were used.

At that time, "code" rubber insulation was generally used for insulated wires and cables in homes and commercial buildings and for lighting in factories. It frequently contained reclaimed rubber and was limited in operation to 50 C. Some 60 to 75 C compounds were used in special cases. The present lowest grade rubber is limited to 60 C operation and 70 to 90 C compounds are available, some of which have improved lives at rated temperatures.

These improvements have been also of benefit for nonleaded cable on a-c network systems of utilities and elsewhere.

One specific development has been the common replacement of natural rubber in insulation by so-called *GR-S* compounds (Buna-S), which were developed early

Fig. 9. Self-supporting aerial cable. Reverse lay facilitates separation of conductors to make taps.

in World War II because of the difficulty then of obtaining natural rubber from abroad.

Another new material has been butyl, a thermosetting compound, developed about 1937. Its commercial use has grown rapidly in the past 10 years, especially for operation up to about 15 kv. In many ways, it has outstanding properties as compared to other rubber or synthetic compounds, as indicated in short- and very long-time tests in air or water either at room temperature or various elevated temperatures. The manufacturers recommend limits of 85 C for normal operation and 100 to 105 C for emergency operation, which are relatively high values.

Early experiences with *GR-S* and Butyl indicated irregularity in quality, but present-day products are generally uniform. Experience with rubber and rubber-like insulations has shown that extreme care must be used in the compounding ingredients and in the processing, and this was found particularly in the early use of some synthetics.

Other Synthetics. Polyvinylchloride insulation (PVC) is used extensively at low voltages in homes and factories. The deficiencies of 20 years ago have been eliminated, and its resistance to oil and chemicals has been of great advantage in factories.

The thermoplastic, polyethylene, was developed before World War II. It has dielectric losses one-tenth those of the best paper-insulated cables and much less than those for rubber and synthetic cable insulations. It has been used extensively on street lighting circuits and in chemical plants, to a limited extent for aerial cables, and still less for underground cables.

Polyethylene is adversely affected by gaseous ionization which may occur in voids formed in the insulation during manufacture or in voids at the conductor or outer insulation shielding because of its high coefficient of thermal expansion. Another limitation is that ordinary polyethylene becomes soft at 105 to 110 C, whereas other insulations can operate for short periods at much higher temperatures.

Some new methods have been developed to raise the temperature limitations either by making additions; or by changing the manufacturing processes, which results in a higher density material; or by irradiating the polyethylene, which results in great increases in allowable temperatures.

Insulations for Hot Locations. The new synthetic, silicone "rubber," comes in a wide variety of characteristics. It has been used to a limited extent in special locations for electric power cables for operation up to 15 kv with conductor temperatures of 125 C or higher. For a given conductor size, the cable is expensive.

Cables with magnesium-oxide insulation and a copper sheath have been made available for operation up to 250 C, except at the fittings, and up to 600 volts.

Aerial Cables. Insulated electric power cables, employing various types of insulation with and without metallic coverings, have been installed overhead. One new trend has been the use of cables insulated with rubber or synthetics and attached to a messenger wire in the field or pre-assembled at the factory. One further improvement has been to incorporate a reverse lay in the conductors in pre-assembled cable, as illustrated in Fig. 9, so that the binding strip may be cut and the three conductors readily spread far enough apart to permit making taps.

HIGH-VOLTAGE CABLES

ANY MATERIAL INCREASES in operating voltage is accompanied by the need for new research, refinements in manufacture, and the development of new installation techniques. The research includes not only new concepts and new tests on materials, but also investigations on the completed cable and associated accessories, especially accelerated aging tests with overvoltage and high temperatures applied for weeks and months. Fig. 10 shows part of one group of test setups. The cable industry has led the electric power industry in making such tests.

Impregnated paper insulation in various designs is still the insulation used for the higher high-voltage cables because of its low dielectric losses, high dielectric strength, good stability, high impulse strength, and comparatively low cost. In recent years, manufacturers have expanded their research facilities.

Increasing attention has been given to impulse strength, which has frequently become important for extrahigh-voltage cable where the insulation thicknesses are small in relation to the operating voltage. Cables are subjected to surges because of switching or arcing at failures, or because of lightning if connected to overhead lines. Impregnated-paper insulation has better impulse strength than the other kinds of commercial in-

Fig. 10. Accelerated aging tests of oil-filled and pipe-type 138-kv 3-conductor cable.

sulation. Its strength increases almost proportionally with the thickness, whereas for most of the other materials little increase is obtained beyond a moderate value of voltage.

Although the use of solid-type insulation has continued for the lower voltages, and low-pressure oil-filled cable is being used up to 230 kv and higher, many new types of impregnated-paper-insulated cables have been developed. These include self-contained, gas-filled cable operating with internal pressures of about 12, 45, or 200 psi; self-contained, oil-filled operating at pressures up to 200 psi; and pipe-type with variations in (1) the insulation, including viscosity of the impregnant; (2) the outer covering of polyethylene or lead, if any, over the insulation of the cable as installed; and (3) the pressure medium (nitrogen or oil).

Self-Contained Gas-Filled Cable. The low-pressure variety of this cable was developed mainly to use gas to monitor the integrity of the lead sheath through indications of gas leaks (Fig. 8). It is similar to solid-type, with some of the compound drained from the insulation. One of the three tubes is solid to insure continuity of gas pressure from joint to joint. Such cable operates at stresses which result in some ionization and formation of wax with a consequent increase in dielectric losses in service. It is applicable for 10- to 40-kv operation.

As the gas pressure increases, the allowable dielectric stresses increase with a consequent reduction in the required insulation thickness. A limited amount of medium-pressure, gas-filled cable has been used at 69 kv.

Considerable high-pressure cable has been used abroad at voltages up to 230 kv and a little has been used here. In Great Britain, there is an experimental installation operating at 275 kv.

Self-Contained Oil-Filled Cable. This was the first type of cable developed in the world for use at the higher voltages, the initial commercial installations being 138-kv low-pressure single-conductor cables in 1927. In 1936, a 230-kv line was installed in Paris, France. In recent years, improvements have been made in the quality of the insulation, as indicated in radial power-factor tests and in over-all tests shown in Table I. Operating experience, results of long-time accelerated life tests in the field, and various factory tests have led to the reductions in insulation thicknesses illustrated in Table II. Fig. 6 shows the highest voltage cable (230 kv) in use in the United States; here, metallized-paper is shown as conductor shielding, but carbon black tapes are also being used, especially abroad.

Medium- and high-pressure oil-filled cables have been used outside this country. In the first category, the usage of pressures of 40 to 75 psi is facilitated by the frequent practice abroad of applying reinforcement over the lead sheath. Fig. 3 shows the 301-kv cable with aluminum conductor and sheath installed in a tunnel in Canada.

Some high-pressure oil-filled cable (150 to 200 psi) has been operating at 380 kv, and above, in Sweden for several years (Fig. 4). In one recent installation there, the oil is circulated to help dissipate the heat. These cables are installed as short lengths in ventilated vertical shafts, which are conditions that do not apply for underground lines in the United States. In such cases or for a short line, it is expected that the circulation scheme will make load capabilities of well over 1 million kva feasible.

Pipe-Type. Although the initial installation of pipe-type cable was made in Europe in 1932, its use in this country has grown rapidly since 1945. Fig. 5 illustrates one type of construction (oil is mostly used in the United States as the pressure medium). The chief economic advantage is that the lengths of cable between joints may be 2,500 feet or more, or a few times the usual lengths of cable in conduits. This results in reduced costs for pulling, manholes, and joints. Over-all economic advantages accrue particularly where conditions are such that only the line itself need be considered for installation, and neither other cables nor a parallel circuit are to be installed in the same route.

Initially, the pipe-type cables were shipped inside a lead sheath, which was removed upon installation. Later, as an economy measure, protective tapes were applied over the insulation, the lead sheath was omitted, and the cable reels had a weather protection covering. Subsequently, substantial improvements were made in the tapes and in the effectiveness of the weatherproof covering.

The magnetic field produced by the line currents causes losses in a steel pipe which increases so fast, percentagewise, with increase in conductor size that the practical limit has been found to be 2,000 MCM (thousand circular mils). In some installations with large conductors, the thermal properties of the soil may be the limiting factor in determining the allowable load for a pipe-type installation. (With self-contained oil-filled cables, the hollow-core segmental conductor construction has been used effectively up to 2,750 MCM, and somewhat larger conductors are practical.)

A large amount of pipe-type cable is in operation in the 110- to 138-kv range and some at 161 to 230 kv in this country.

ACCESSORIES

Connectors. For both low- and high-voltage cables, the use of pressed connectors has increased considerably for all types of conductors (Fig. 11). Pressed connectors may be of the indent type, which requires a shield to produce a uniform field, or of the circumferential type.

Insulating Tapes. The tapes previously in common use for building joints and potheads were varnished cambric, which had the disadvantages for high-voltage use of high power factor and deleterious effects on oil. Similar tapes with an oil-resistant covering were developed, but in recent years the use of impregnated-crepe-paper tapes has grown rapidly. Its stretchability and

Fig. 11. A 4-ram hydraulic press makes connections on 2,000 MCM segmental conductor in 138-kv pipe-type cable.

freedom from slipping are of considerable advantage. For some applications, the use of straight-paper tapes has been found to be of advantage in keeping down the diameter of the applied insulation.

Joints and Potheads. In the past 20 years, a number of long lines of 3-conductor low-pressure oil-filled cables with oil-stop joints, have been installed, as illustrated in Fig. 12.

Developments have been made in potheads for all voltages, such as solder seals instead of gaskets between porcelain and metal, improved designs to control the electric stresses, improved provisions for thermal expansion, and designs to withstand higher internal pressures (Fig. 13).

In recent years, epoxy resins with or without fabric tapes have been used to advantage in making joints and potheads on lower voltage cables. The adherence and inertness of the material has resulted in its use in joints between paper- and rubber-insulated cables. (It is sometimes used also to cover cracks in external insulating sleeves and lead sheaths.) A recent foreign development is the use of epoxy insulation in extrahigh-voltage potheads and joints. One special use is illustrated in Fig. 14. The high electrical strength of epoxy insulation is obtained only when it is so applied that it is free of voids.

Auxiliary Equipment. For self-contained oil-filled cables, variations in oil volume with temperatures are handled usually by reservoirs. In Canada, a pumping plant was installed instead of reservoirs. A reinforced lead sheath (with three conductors in line) has been used some abroad as a diaphragm to compensate for volume variations.

In recent years, apparatus has been installed to provide continuous circulation of oil inside self-contained and pipe-type cable, usually in short installations. This scheme not only considerably increases the possible loads which may be carried at low and medium voltages, but also may make feasible the use of short connections operating at, say, 500 kv or more, even with very high dielectric losses. Other schemes of special cooling, which employ water, have appeared.

MANUFACTURING TECHNIQUES

INDICATIONS have already been given of the many advances made by the manufacturers. For rubber and synthetic insulation, new machines and processes have been developed to improve the concentricity, uniformity, and other mechanical properties; methods have been introduced for continuous extrusion and vulcanization (horizontal and vertical) at high speeds; and electrical testing techniques have been introduced to check more thoroughly the finished product.

Additional improvements in paper-insulated cables include improvement in tapes, in impregnants, in taping machines (to obtain proper tension and spacing of the tapes), in take-up apparatus at the end of the taping machines, and in the drying and impregnating processes. In some cases, as much as one inch or more of insulation may be applied in one operation.

Suitable schemes have been worked out for the continuous extrusion of lead sheaths, including copper bearing lead (but not most alloys), and for the direct extrusion of aluminum sheaths. Other special developments include the facilities for armoring lengths over 30 miles long (Canada), and for manufacturing single 16-mile lengths of submarine cable (Great Britain).

INSTALLATION TECHNIQUES

CONDUIT SYSTEMS continue to be used for most underground cable in this country, but the percentages of cables installed directly in the earth and in pipe have increased. In addition, there is a growing trend toward the use of various types of cable in air outdoors and in industrial structures and the buildings of utilities.

Underground Conduits. Improvements here include increasing the smoothness of the inside of the ducts; large increase in length of sections between manholes; improved contour of ducts between manholes; changes in construction to avoid injury to the cable at the duct mouth entrance in manholes; and better design of manholes to accommodate cable movement and to avoid premature sheath cracking in service.

Fig. 12. Stop joint in 3-conductor 69-kv oil-filled cable with taping completed on two conductors.

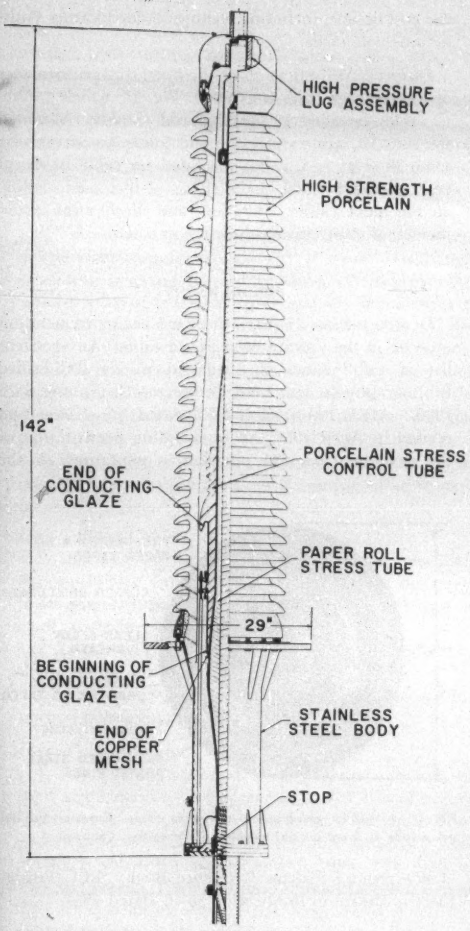

Fig. 13. A 230-kv termination for high-pressure pipe-type cable.

Installing Lines. Other developments in field practices include some increase in use of three single-conductor cables in a duct; new types of apparatus for pulling cable into a pipe to minimize exposure of cable and to increase speed in installation (Fig. 15); improved training of splicers and development of special tools and equipment for their use; and introduction of various schemes of minimizing contamination during construction of high-voltage joints because of moisture and dirt, such as the use of trailers over the manhole openings and the use of air-conditioning equipment.

Submarine Cable. The world has seen some very unusual installations of submarine cable in the past few years as indicated in the following:

1. Four 34-mile lengths of 69-kv solid-type cable across the St. Lawrence River, northeast of Quebec, Canada. Fig. 16 shows the construction used except for the shore ends.
2. Five 16-mile lengths of self-contained, high-pressure, gas-filled, 138-kv cable at Vancouver, Canada (Fig. 17).
3. Sixty-mile length of concentric 100-kv d-c cable in the Baltic Sea to Gotland. (D-c installation is to be installed across the English Channel.
4. Two 1.3-mile lines of high-pressure oil-filled pipe-type cable in the New York harbor.
5. Four 1.7-mile lengths of 115-kv low-pressure oil-filled cable across Lake Champlain.

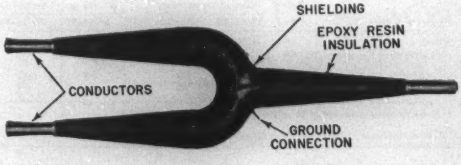

Fig. 14. Factory-insulated connector for 69-kv Y-joint in pipe-type cable. (Made in Italy for application in United States.)

Soil. Increased attention is being paid to the soil placed around buried cables, pipes, or conduits, in order to insure that the soil in the final installation will not act as a limitation on the allowable loading of the cable. The problem is accentuated for installations where the permissible maximum conductor temperatures or the daily load factor, or both, are high. At the higher temperatures, the soil tends to dry out considerably, with a resultant large increase in thermal resistivity.

In some instances, these various problems have led to the use of special backfill of sand and small stones or to installing the cable about 6 feet deep to take economic advantage of the better heat dissipation in presence of increased moisture.

Fig. 15. Installing pipe-type cable. Each trailer contains a reel of one-conductor cable. Three cables pass over large sheave wheel into flexible steel tube and thence into underground pipe.

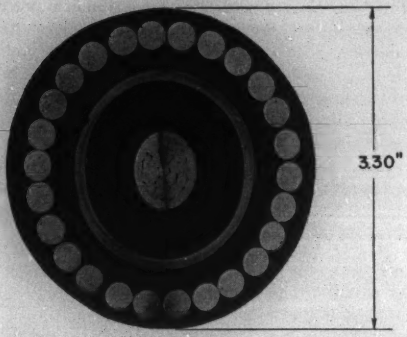

Fig. 16. A 69-kv solid-type submarine cable with oval copper conductor, lead-sheath and aluminum-wire armor. (Made in Canada; installed in St. Lawrence River.)

OPERATION

Temperatures. The loading and operating temperatures of underground lines have been increased in the past 20 years (see Table III). The cable fraternity in the United States has led the electric power industry in establishing special temperatures for emergency operation. In many installations where two or more lines are in parallel, the emergency load capability determines the over-all firm capacity of the power supply.

Table III. Standard Maximum Allowable Operating Temperatures

		Temperature—C			
	Rated	Normal Operation		Emergency Operation	
Type of Cable	(Kv)	1934-38	1951-58	1934-38	1951-58
Solid, 1-conductor	15	81	81	None	96
and shielded 3-conductor	69	60	60	None	70
Oil-filled*	26-75	75	75	80	95
	76-138	70	70	75	90

* Temperatures also apply to pipe-type cable in later period.

NOTE: Industry is preparing to increase the temperature limits.

Surveys. Coincidental with this interest in and use of higher loadings has been an increase in some instances in special measures, such as the previously mentioned attention paid to soils; periodic surveys of duct and soil temperatures; corrosion surveys; etc.

Maintenance. With insulation thicknesses reduced, loadings and voltages increased, the need for adequate maintenance has been accentuated. This includes inspection and repairs of equipment in manholes and at terminals on a reasonably regular and prompt new basis. New techniques for making repairs to pipe-type and other new types of cable have been evolved.

Fault Location. With the installation (1) of underground lines having many taps, (2) of extrahigh-voltage lines, where the resistance of a failure is high, and (3) of lines with long lengths between joints, the need has grown for developing apparatus which would make possible the prompt and accurate location of failures. This need has been satisfied by a few new developments in the past decade, including techniques for locating faults in pipe-type cable.

Failures. An indication of the operating performance of high-voltage lines is given in Fig. 18, which applies to cables installed in underground conduit. Although the rates of failures of cable and joints was decreasing some 30 years ago, it has increased for cable in recent years mainly because of the effects of increased loading on the older cables, corrosion, and mechanical injury incidental to increased construction activities.

BIBLIOGRAPHY

DURING the last 25 years, there has been a tremendous increase in the literature on power cables. An excellent list of publications is contained in the "Classified Bibliography on Insulated Conductors Beginning with 1930," AIEE Publication S-73, dated June 1954 and revised in April 1956. An outstanding presentation of the developments and practices is contained in the

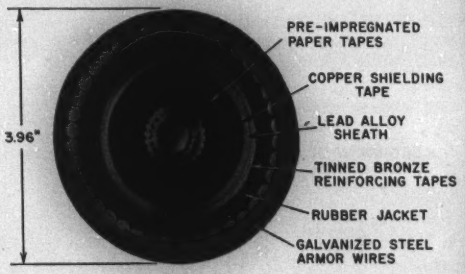

Fig. 17. A 138-kv gas-pressure submarine cable. Operates at 300 psi. (Made in Great Britain; installed at Vancouver, Canada.)

"Underground Systems Reference Book," EEI (Edison Electric Institute) Publication 55-16, dated 1957.

THE FUTURE

ALTHOUGH MUCH PROGRESS has occurred in the power cable field, many problems still lie ahead. An outline of some avenues for further development and improvement follows:

Conductors.

1. Increase the practical maximum conductor size for pipe-type cable above 2,000 MCM, perhaps by the use of nonmagnetic or nonmetallic pipes.
2. Improve the cleanliness of conductors for extra-high-voltage cables to improve the adjacent insulation.
3. Develop optimum annealing for compacted large conductors of single-conductor and 3-conductor cables to facilitate handling and training without leading to troubles with sheaths or insulation.

Sheaths and Coverings.

1. For lead alloys, increase knowledge of properties

and improve manufacturing to eliminate infrequent troubles with cracking upon installation and to improve mechanical properties.

2. For aluminum sheaths, increase knowledge of allowable bending strains and tensile stresses. Also, continue developments to produce long cable lengths, sound sheath, special constructions such as corrugations, and reliable methods of attaching joint casings to sheaths.

3. For nonmetallic coverings, the following desired developments apply to some or all types: (1) change composite coverings to reduce costs; (2) improve the concentricity of extruded coverings; (3) demonstrate a life of 35 years or more; (4) improve adherence; (5) develop coverings with increased resistance to high normal and transient temperatures; and (6) improve synthetics to reduce the effect of exposure to air, oil or chemicals. Also develop nonmetallic covering for paper-insulated cable.

4. Develop improved low-cost corrosion-resistant pipe coatings which will retain their insulating value in service.

Low-Voltage Cables.

1. Improve solid-type and low-pressure, gas-filled paper-insulated cable to reduce increases in dielectric losses in operation. (Fig. 7 illustrates increases found in cable made in recent years.)

2. Improved control of uniformity of rubber and synthetic insulations.

3. Develop synthetic insulations of reasonable cost for normal operation at 100 to 150 C.

High-Voltage Cables.

1. Develop underground cable and cable systems of high load capability for operation at 345 kv and higher under American conditions. (A large experimental installation of five designs of 345-kv cable at Cornell University is scheduled for the end of 1959. The Association of Edison Illuminating Companies (AEIC) and EEI are sponsoring a 3-year test program, in which several American cable, cable accessory and equipment manufacturers have been co-operating. The results are expected to bring improvements also in installations in the 69- to 287-kv range.)

2. Carry forward developments in materials, including impregnants, and in processing to improve electrical stability of insulation and mechanical properties. (With present minimum power factors of 0.2 to 0.3 per cent for high-voltage cable insulation, the dielectric losses limit seriously the load capabilities, and an increase to only 0.6 per cent in service would permit very little load current for 345-kv cable.)

3. Increase dependable 60-cycle and transient dielectric strengths.

4. Improve and develop synthetics, to permit use in extrahigh-voltage lines. (Since the charging current will limit the allowable length of such lines employing paper insulation, the development of a synthetic with low dielectric constant might be needed for very long lines.)

5. Make improvements to permit higher normal and emergency loading.

6. As the need arises, extend studies for special applications such as extrahigh-voltage d-c cable and accessories and cable for nuclear-power stations.

7. Develop short-time test to give serviceability information comparable to that gained in long-time accelerated life tests.

Accessories.

1. Extend developments such as the use of epoxy resins for field construction and for prefabricated parts of joints and potheads.

2. Develop improved special designs, such as stop joints for oil-filled self-contained cable and tapped joints for various cable types operating at the higher voltages.

3. Develop special heat-dissipation facilities, including forced cooling, for extrahigh currents (generator leads) and extrahigh-voltage cable.

4. Reduce number of designs of joints, potheads, and other accessories.

Installation and Operation.

1. Increase allowable loading of underground lines by better understanding of thermal properties of soils, by the use of suitable backfill, and by expanded programs of temperature surveys and controls.

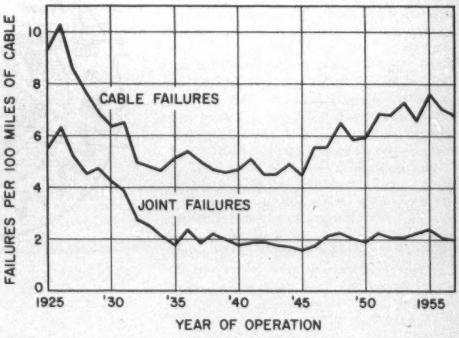

Fig. 18. Rates of failure for underground lines operating at more than 7.5 kv.

2. Improve the training of splicers and field supervisors where necessary to bring installation methods to factory-production standards.

3. Improve the examination of failures where indicated to help in operation and to point up needed improvements.

4. Develop new methods of installing cable and accessories to decrease cost or increase service reliability.

5. Obtain savings by increased use of aerial and directly buried cable, and by increasing the cable occupancy of conduits.

6. Obtain optimum manhole design from further studies of effect of cable movement on sheath life.

CONCLUSION

PRESENT INDICATIONS lead to the expectation of continued rapid growth of the use of electric power which will create new problems and challenges throughout the entire cable field. Increased use can be expected especially for the lowest and highest voltage cables.

Wider use of lower-voltage cable will point up the need for greater economy through the use of simple and inexpensive but reliable cable and accessories, and through simplified installation methods.

The transmission of large blocks of power will increase in size and number, in part because of the growth in size of generating units, the frequent remoteness of new stations from centers of utilization, and the installation of interconnections. This trend will sharpen the need for extrahigh-voltage underground lines of large load capability.

The demand for increased economies in view of rising costs and for reliable operation during a 35- to 50-year life will emphasize the need for carrying forward present standards and for continuous improvements in materials, designs, factory processes, installation methods and workmanship, and maintenance procedures.

A review of the accomplishments of the past 25 years makes it reasonable to expect that the next 25 years will bring not only solutions to present problems but startling new developments.

INSTITUTE ACTIVITIES

AIEE Middle Eastern District Meeting To Be Held in Baltimore, Md., May 19-21

THE AIEE Middle Eastern District Meeting to be held at the Lord Baltimore Hotel, Baltimore, Md., May 19-21, 1959, will feature 135 technical papers presented by outstanding speakers from many parts of America as well as Europe. Interesting inspection trips, closely allied with the technical sessions, will be plentiful because of the prominence of Baltimore as a nucleus for many leading industries. Scenic tours, including a trip to historic Annapolis, have been arranged specifically to appeal to the ladies and the program of social affairs will be educational and entertaining for all.

General Session

The general session will be held in the Calvert Room of the Lord Baltimore Hotel on Tuesday, May 19, at 10 a.m.

L. F. Hickernell, president of AIEE, will briefly discuss the accomplishments and plans of the Institute, and Dr. B. R. Teare, Jr., vice-president of District No. 2, will welcome those attending the meeting. A formal address, on a subject of utmost importance to the profession, will be delivered by an outstanding personage.

Technical Sessions

The program of technical sessions has been carefully planned around a host of papers by authors from as far away as California in the west and Paris, France, in the east. Included will be such timely subjects as a five-paper session on satellite tracking. The two principal methods of satellite tracking will be described by authors from military (U. S. Naval Research Laboratory) and civilian electronic laboratories. Papers on computers and automatic programming cover not only new uses in industry, but also the expanding use of these devices in the utility field. The session covering the use of epoxy resin formulations for joints, terminations, and cable sheath repairs will be of interest to those working in the power field as well as those engaged in communications work.

Special Sessions on Education and Management

At a time when our engineering educational system is being re-evaluated as a result of the technological progress in other countries, the Engineering Education Session papers will be both stimulating and challenging to those within the profession.

During the present competitive-type recovery period of business, effective management is becoming increasingly important, consequently, the Engineering Management Session will be extremely valuable to all attending.

Registration

Registration facilities will be located on the mezzanine of the Lord Baltimore Hotel. For those arriving on May 18, the registration desk will be open from 7:30 p.m. until 9:30 p.m. During the meeting, registration hours will be from 8:00 a.m. to 4:00 p.m., except on the final day, Thursday, May 21, when the registration desk will close at 12:00 noon.

Registration fees: Members, $3; Nonmembers, $5; Student Members, no fee; wives of registrants, no fee.

Please return advance registration cards (enclosed in mailed announcement) early with an indication of the activities that you plan to attend. This will give the committees an opportunity to make adequate provisions for all affairs. Do not send money with registration.

It is recommended that immediately upon completing registration at the hotel, you procure tickets for the inspection trips, the smoker, the dinner-dance, and the ladies' activities.

Hotel Reservations

A block of rooms has been set aside at the Lord Baltimore Hotel, Baltimore and Hanover Streets, to accommodate those planning to attend the meeting. The hotel reservation card accompanying the mailed announcement should be completed and returned promptly to the Lord Baltimore Hotel. Rates per day are as follows:

Single Room (one person) ...	$8.00 to $14.00
Double Room—Double Bed (two persons)	$9.50 to $18.00
Double Room—Twin Beds (two persons)	$11.00 to $18.00
Suites—Parlor, Bedroom, and Two Baths	$23.00 to $37.00

Social Activities

Smoker. On Tuesday evening, May 19, there will be a smoker in the Calvert Ballroom of the Lord Baltimore Hotel. The cocktail hour will start at 6:30 p.m. and dinner will be served immediately thereafter. Following dinner, there will be an entertaining floor show with a variety of acts. This smoker, priced at $7.50, promises to be a superlative evening, and one that should not be missed.

Dinner-Dance. On Wednesday evening, May 20, the mammoth dinner-dance will be held in the Calvert Ballroom. Cocktails will be available until the dinner starts at 7:00 p.m. The dance will start at 9:00 p.m. and continue until 1:00 a.m. The price is $7.50 per person. Setups are available during the dance.

Ladies Program

An interesting program for the wives of the men attending the meeting has been carefully planned by Mrs. Paul Betz and her Ladies Committee.

Tuesday morning, there will be a prolonged coffee hour in the ladies hospitality rooms. Hostesses will be in attendance to greet guests. There will not be scheduled entertainment during the opening day as the Committee feels that the ladies would enjoy visiting department stores and shops, or possibly the Walter's Art Gallery. The latter is situated at Mt. Vernon Place, which is recognized for its famous statues throughout the east. The Peabody Conservatory of Music and the Maryland Historical Society are located on this famous Square. An interesting sightseeing tour of the city can be arranged at a nominal cost.

At 6:00 p.m., the ladies will gather for cocktails and dinner followed by a card party. The committee has planned a delightful evening for the ladies while their husbands attend the smoker.

Wednesday morning, a coffee hour will be held in the hospitality rooms, followed by an all day trip to historic Annapolis, the capital of Maryland, and the site of the U. S. Naval Academy. Busses will leave the hotel and go via "Old Towne" (early Baltimore) and through the Harbor Tunnel. The first stop in Annapolis will be for luncheon at the Treadway Inn. After luncheon, there will be a tour of Annapolis, famous for its Colonial architecture, a visit to the Governor's Mansion, and a trip to the Naval Academy, where visitors will witness a full dress parade of the entire Midshipman Brigade.

Thursday morning, there will be a final coffee hour. A warm welcome is extended to the ladies who are asked to write a note to Mrs. Paul Betz, chairman, Ladies Committee, 1113 Argonne Drive, Baltimore 18, Md., telling her that they plan to be present.

Inspection Trips

A program of inspection trips of both technical and general interest has been arranged. Because the number of persons who may be accommodated on each of these trips is limited, you are urged to make arrangements and obtain full details at the inspection trips desk immediately after registering at the Lord Baltimore Hotel.

Black & Decker Manufacturing Company (B & D), Hampstead, Md. (Tuesday afternoon) B & D is one of the world's largest plants devoted exclusively to the manufacture of electric tools. The tour will consist of a guided inspection of all manufacturing and assembly operations and facilities. In its course, visitors will see steps in the manufacturing of B & D products such as motor winding, sheet metal working (high-speed lamination

presses), automatic buffing of aluminum castings, a conveyorized paint system with bonderizing ovens, steel coil slitting operations, forging operations, tool assembly, inspection, and packaging. Side trips will be made to the plant's power house and substations. Sufficient time will be available for a question and answer session at the end of the tour. Lunch will be served in the B & D cafeteria at 1:30 p.m. Bus leaves Lord Baltimore Hotel at 12:00 noon, returns 5:15 p.m. Reservation $2.50 (complimentary lunch included).

Westinghouse Electric Corporation, Air Arm Division, Baltimore, Md. (Tuesday afternoon) The Air Arm Division of Westinghouse is engaged in the development, design, and manufacture of military airborne electronics systems in the following categories: fighter armament control, bomber defense, missile guidance, flight control, special purpose systems, and astronautics. A guided inspection of the most interesting parts of this tremendous plant will include the Engineering Laboratory where there is environmental testing equipment; the vacuum impregnation of silicon vinyl epoxy, and "Fosteriting" which is a patented Westinghouse process for encapsulating transformers for high temperature as well as a protection against moisture; and the Plating Room which has facilities for the process of etching circuits using either Chronar or Mylar film negative and sensitized boards. Also included is the power house which employs the network type of distribution for plant power. Lunch will be served in the Westinghouse cafeteria prior to starting this tour. Bus leaves Lord Baltimore Hotel at 12:30 p.m., returns 4:15 p.m. Reservation $1.50 (complimentary lunch included).

Herbert A. Wagner Generating Station, Baltimore Gas & Electric Company (Wednesday morning) The Herbert A. Wagner Electric Generating Station, located on the south side of the Patapsco River about 7 miles southeast of the center of Baltimore City, is the newest plant on the Baltimore Gas & Electric Company's system. The first turbine generator, rated at 125,000 kw, was placed in commercial operation early in 1956, and a second similar unit went on the line January 20, 1959. The throttle steam conditions for both units are 1,800 psig and 1,000 F, with reheat to 1,000 F. Each generator is connected to a 160,000-kva autotransformer through which its output is fed into the company's 110,000-volt transmission system. Bus leaves Lord Baltimore Hotel at 8:30 a.m., returns 11:45 a.m. Reservation $1.50.

The Martin Company, Baltimore, Md. (Wednesday morning) The Space Flight, the Nuclear, and the Baltimore Divisions, located on an 1,100-acre tract to the east of Baltimore, at present employ 19,000 persons. This facility includes its own privately owned airport and seaport. Products include nuclear power supplies, jet seaplanes, various missiles, space vehicles, electronic systems, and ground support equipment for missiles, rockets, and aircraft. The visitors will see airframe, electrical and electronic manufacturing areas, electrical and electronic tooling and testing, parallel operation of airborne a-c generators, the electrical test facility, and the seaplane launch area. Bus leaves Lord Baltimore Hotel at 8:15 a.m., returns 12:45 p.m. Reservation $1.50.

Bethlehem Steel Company, Sparrows Point, Md. (Wednesday afternoon) The Bethlehem Sparrows Point plant is one of the largest steel plants in the world. This plant consumes 1/400 of all the electric power generated in the Nation and it is said that if the plant's electric power lines were strung end to end they would reach halfway around the world. The guided tour will include the coke oven area, Open Hearth No. 4, the new slatting mill, the new plate mill, Tandem Mill No. 3, the 68-inch hot strip mill, and the tinning lines. Lunch will be served at the plant at 1:15 p.m. Bus leaves Lord Baltimore Hotel at 12:30 p.m., returns 5:15 p.m. Reservation $1.50 (complimentary lunch included).

Ballistic Research Laboratories, Aberdeen Proving Ground, Aberdeen, Md. (all day Thursday) The Ballistic Research Laboratories were established by the Ordnance Department for basic and technical research in ballistics, the related fields of physics, chemistry, mathematics, and engineering. A guided tour will include the Computing Laboratory where the firing tables for artillery and guided missile weapons are prepared, the free flight range for the measurement of aerodynamic forces, the first supersonic wind tunnel built in this country large enough for practical tests of projectile and guided missile models, and the satellite tracking station where there are instruments capable of tracking current satellites for several thousand miles and with a theoretical capability of tracking a space ship to the moon. The tour will close with a visit to the Ordnance Museum. Lunch will be served in the dining room. Bus leaves Lord Baltimore Hotel at 8:30 a.m., returns 5:00 p.m. Reservation $3.50 (transportation $2.50, lunch $1.00).

General Committee

The General Committee includes: P. L. Betz, chairman; P. P. Ives, secretary; H. A. Frey, technical meetings & papers; T. W. Trice, general session; T. H. Marshall, Jr., arrangements; W. B. Mann, finance; C. B. Bechtel, registration; R. C. Desor, inspection trips; L. J. Frisco, student activities; L. J. Huettel, entertainment; Mrs. P. L. Betz, ladies' activities; J. I. Elliott, publicity; G. H. Carden, Section chairman.

Mailed Announcement

A mailed announcement of this meeting will be sent to members in District No. 2. If a copy is desired by members in other Districts, please write to E. C. Day, Assistant Secretary for Technical Papers and Programs, TOD, American Institute of Electrical Engineers, 33 W. 39th St., New York 18, N. Y.

Technical Program

The tentative technical program for the meeting follows.

Tuesday, May 19

2:00 p.m. Computers and Automatic Programming—I

G. B. Fallon, Session Chairman
Fairmount Room

DP59-641 Use of Automatic Programming Techniques for Solving Engineering Problems. *J. T. Carleton, N. Chacken, T. W. Martin,* Westinghouse Electric Corp.

DP* Current Status of Automatic Programming for Data-Processing Problems. *Dr. G. M. Hopper,* Remington Rand Univac

DP* Automatic Programming Systems. *Col. Alfred Asch,* Headquarters Air Materiel Command, USAF, Wright-Patterson Air Force Base

DP* Fortran—A Close Look at an Automatic Coding System. *J. T. Ahlin, W. P. Heising,* International Business Machines Corp.

DP* Pilot—The New NBS Multicomputer Data-Processing System. *A. L. Leiner, W. A. Notz, J. L. Smith, A. Wineberger,* National Bureau of Standards

2:00 p.m. Power Stations and Substations

D. H. Sandell, Session Chairman
Federal Hill Room

DP* Discharge Electrodes for Electrostatic Precipitators. *J. S. Lagarias,* Koppers Company

DP* Selection, Operation, and Maintenance of Station Control Batteries. *W. C. Wheeler,* Baltimore Gas & Electric Co.

CP58-1287 Evaluation of Two Basic Shapes of Conductor Grooves for Aluminum Power Connectors. *Walter Frank, M. R. Monashkin,* U-I Division, Burndy Corp.

58-1288 Preparation of Aluminum Conductors for Stable Electric Connectors. *M. R. Monashkin,* U-I Division, Burndy Corp.

58-1197 Design and Analysis of Unplated High-Pressure Limited Area Bolted Electric Joints Including a Method of Calculating the Various Components in Joint Resistance. *R. K. Allen,* General Electric Co.

2:00 p.m. Power Systems Operation

W. M. Hanna, Session Chairman
Founders Room

DP* A-C Network Size as Determined by Service Restoration Consideration. *H. D. Cassard, Jr.,* Baltimore Gas & Electric Co.

DP* Practical Microwave Applications to Utility Problems. *D. F. Burnside,* Westinghouse Electric Co.

DP* Automatic Peaking Plant. *B. H. Hefner,* General Motors Corp.

DP* Automatic Assembly of General System Trouble Reports. *C. D. Alvey,* Baltimore Gas & Electric Co.

2:00 p.m. Industrial Equipment and Controls—I

I. L. Cooter, Session Chairman
Mt. Vernon Room

DP* Technological Advances in Packaged Electrical Adjustable Speed Drives. *V. R. Murphy,* Reliance Electrical and Engineering Co.

*District Papers will not be printed by the Institute; however, they may be available at the meeting at the discretion of the author.

CORRECTION—In the January 1959 *Electrical Engineering*, p. 120, under "New Books," the number of pages in "Elsevier's Dictionary of Nuclear Science and Technology" was incorrectly noted as 91 pages. The dictionary, published by D. Van Nostrand Company, Inc., contains 914 numbered pages.

DP* Low-Voltage Single-Phase Power Systems for Transportation Equipment. *W. J. Kutcher*, Square D Co.

DP* Electrical Equipment Selection—A Case History for Cement Plants. *W. E. Korsan*, Allis Chalmers Mfg. Co.

DP* Static Control Equipment for Precise Frequency Conversion Motor Generator Set. *R. L. Robertson, P. D. Brohaugh*, Allis Chalmers Mfg. Co.

DP* Static Power Supply for 150-Hp D-C Motor. *R. P Lange, W. E. Cronquist*, General Electric Co.

2:00 p.m. Measurements and Testing—I

A. H. Kidder, Session Chairman
Phoenix Room

DP* Design Considerations for Automatic Electronic Test Equipment. *D. H. MacDonald, D. E. Schwartz*, Bendix Radio

DP* Instrumentation and Control System for the Westinghouse Testing Reactor Critical Experiment. *F. L. Kelly*, Westinghouse Electric Corp.

DP* A Nonmechanical Device for Totalizing Electrical Impulses. *M. F. Borleis*, Baltimore Gas & Electric Co.

DP* Relay Logic Circuits in Missile System Simulators. *W. E. Mann*, Aircraft Armaments

DP* Planning Reliability into a New Relay Component. *W. H. Lesser*, General Electric Co.

2:00 p.m. Satellite Tracking

T. M. Linville, Session Chairman
Calvert Room

DP* Low Signal Level Missile Instrumentation. *L. G. DeBey*, Ballistics Research Laboratory, Aberdeen Proving Ground

DP* AESOP—An Artifical Earth Satellite Observation Program. *R. L. Easton*, U. S. Naval Research Laboratory

DP* Doploc Tracking Filter. *V. W. Richard*, Ballistic Research Laboratories, Aberdeen Proving Ground

DP* Microlock Capabilities and Limitations. *W. F. Sampson*, Hallamore Electronics Co.

DP* ELSA, a Dual-Purpose Receiver for Satellite Instrumentation. *K. H. Patterson*, Ballistics Research Laboratories, Aberdeen Proving Ground

Wednesday, May 20

9:00 a.m. Measurements and Testing—II

Dr. E. F. Wolf, Session Chairman
Phoenix Room

DP* A New Naval Facility for Measuring Stray Magnetic Fields. *W. Anderson*, U. S. Naval Engineering and Experiment Station

DP59-642 A Thickness Indicator for Electroless Plating. *J. R. Hunsberger, A. F. Welch*, General Motors Corp.

DP* Test Equipment Design Philosophy. *Gordon Walker*, General Electric Co.

DP* An Economical 230-Kv Metering Installation with Remote Indication of Kilowatt Hours. *M. F. Borleis*, Baltimore Gas & Electric Co.

9:00 a.m. Power Transmission and Distribution—I

Gen. L. G. Smith, Session Chairman
Calvert Room

DP59-643 Radio Influence Voltages Caused by Surface Imperfections on Single and Bundled Conductors. *T. W. Liao*, General Electric Co.

DP* Economic Factors in Power Transmission. *R. C. R. Schulze*, Atlantic City Electric Co.

58-1274 Tests on Protective Gaps for Distribution Series Capacitors. *N. W. Neagle*, General Electric Co.; *H. E. Weaver*, Commonwealth Edison Company

58-1242 Two Examples of Industrial Research in France Relating to the Transmission of Electrical Energy. *F. N. Cahan, R. A. Tellier*, Electricite de France

DP59-644 A New Approach to the Calculation of the Lightning Performance of Transmission Lines—II. *Dr. C. F. Wagner, A. R. Hileman*, Westinghouse Electric Corp.

9:00 a.m. Industrial Equipment and Controls—II

C. T. Pearce, Session Chairman
Mt. Vernon Room

DP* Multiple Channel Control and Indication Systems Utilizing a Single Pair of Wires. *Addison Davidson*, FEMCO, Inc.

DP* HWR-D-C Crane Hoist Control for A-C Power Installations. *C. C. Davies, A. H. Myles*, Square D Co.

DP* Arc Suppression Techniques and Devices. *F. Miller*, Square D Co.

DP59-645 Electromagnetic Brake with Controllable Torque. *C. A. Lister*, Square D Co.

9:00 a.m. Feedback Control Systems

Adam Kegel, Session Chairman
Founders Room

59-646 Predicting the Performance of a Wind Tunnel Regulating System Using an Analog Computor. *R. Herbst, J. O. Nichols, F. W. Keay, R. W. Miller*, Westinghouse Electric Corp.

59-647 A New Chart Relating Open- and Closed-Loop Frequency Responses of Linear Control Systems. *C. F. Chen, D. W. C. Shen*, Moore School of Engineering, University of Pennsylvania

CP58-1302 Digital Computer Study of Third Order Nonlinear Servomechanism. *Y. H. Ku, K. Fukunaga*, Moore School of Engineering, University of Pennsylvania

DP59-648 Near Optimum Characteristics of a Series Motor Relay Servo. *P. Gowlow, A. P. Stockebrand, G. J. Thaler*, U. S. N. Postgraduate School

DP59-649 Stability Criteria for Instrument Servomechanisms with Coulomb Friction and Stiction. *M. P. Pastel, G. J. Thaler*, U. S. N. Postgraduate School

9:00 a.m. Engineering Management—I

Dr. F. Hamburger, Jr., Session Chairman
Federal Hill Room

DP* Management Looks at Productive Maintenance. *C. E. Sutton, Jr.*, General Electric Co.

DP59-650 Effective Organization—A Case History. *W. R. Brown*, The Martin Company

DP59-678 Peripheral Professional Problems of a Manager. *C. F. Savage*, General Electric Co.

DP59-651 Design in the Evolution of Products. *G. A. Beck*, General Electric Co.

DP* Use of Statistical Methods in Product Engineering. *D. E. Garrett*, General Electric Co.

9:00 a.m. Switchgear

W. C. Feaster, Session Chairman
Fairmount Room

DP* Developments in Metal-Clad Switchgear. *J. J. Torbit*, General Electric Co.

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DP59-652 A New Regulator By-Pass Switch. *W. C. Davis*, General Electric Co.

59-679 A Line of Outdoor Single-Tank Oil Circuit Breakers for 14.4 through 46-Kv Service. *C. J. Balentine*, General Electric Co.

DP59-653 Magnetic Loop Contacts for Outdoor Group-Operated Switches. *Eugene Gorin*, MEMCO Engineering & Mfg. Co.

59-654 Aluminum Bus for Shipboard Application. *G. J. Thompson, S. H. Behr*, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

2:00 p.m. Microwave Systems and Equipment

W. C. Warman, Session Chairman
Calvert Room

DP* Transistor Audio Tone Equipment Design Techniques. *R. H. Kline*, Westinghouse Electric Corp.

DP* Design of Directional Couplers for Use in Microwave Test Equipment. *G. L. Allerton*, Western Electric Co.

DP* A New High-Capacity Microwave Relay System. *C. G. Arnold*, RCA, New York, N. Y.; *D. E. Isaac*, RCA-Victor Ltd., Montreal, Canada; *H. R. Mathwich, R. F. Privett, L. E. Thompson*, RCA, Camden, N. J.

2:00 p.m. Computer Application in the Electric Power Industry

W. C. Marble, Session Chairman
Fairmount Room

DP* Location of Shunt Capacitors on a Loss Reduction Basis Utilizing an IBM 650. L. J. *Rankine*, IBM

DP59-655 New Computer Programs Expand the Service Available to the Utility Industry. *R. W. Long, R. T. Byerley, L. J. Rindt*, Westinghouse Electric Corp.

DP* Natural Frequencies of Stacks Calculated by Means of the Digital Computer. *D. D. Williams, Miss L. M. Benson*, Baltimore Gas & Electric Co.

CP58-1217 Transmission and Distribution Interruption Records by Mechanical Accounting Methods. *J. R. Gummersall, Jr.*, Long Island Lighting Co.

2:00 p.m. Rotating Machinery—I

R. H. Riley, Jr., Session Chairman
Founders Room

DP59-656 Failure of Commutator Leads on High-Speed Armatures. *R. L. Claggett, J. L. Bennett*, Black & Decker Mfg. Co.

CP59-126 A Bridge Circuit for Measuring Temperature of Alternating Current Energized Windings. *R. E. Seeley*, General Electric Co.

DP59-657 Torsional Vibrations of Motors Geared to Compressor Drives. *P. B. Thames, T. C. Heard*, General Electric Co.

DP* Thermal and Overload Protection of Hermetic Motors in Air Source Heat Pump Compressors. *V. H. Eargle*, General Electric Co.

2:00 p.m. Electrical Systems for the Metals Industry

T. S. Novak, Session Chairman
Mt. Vernon Room

DP* Continuous Cable Stranding and Induction Stress Relieving. *G. F. Bobart, S. V. Stickler, Jr.*, Westinghouse Electric Corp.

DP* Design of D-C Motors for Modern Slabbing Mill. *R. M. Dunaiski*, General Electric Co.

DP* Programming Control for the Steel Industry. *P. A. Travisano*, General Electric Co.

DP* Speed Regulation Equipment on a Hot Strip Mill. *A. J. Wuebeen*, Allis Chalmers Mfg. Co.

DP59-658 Innovations in Control of Continuous Steel Processing Line. *W. A. Duerkop*, United States Steel Corp.

DP* Magnetic Amplifier Control for Electric Arc Furnaces. *R. A. Geiselman*, Westinghouse Electric Corp.

2:00 p.m. Epoxy Resins for Cable Systems

J. W. Anderson, Session Chairman
Phoenix Room

59-659 Epoxy Resin–Orlon Cable Terminations for 33-Kv Service. *P. L. Betz, O. W. Lusby, J. J. Rueckert, J. F. Foley, M. B. Gordon*, Baltimore Gas & Electric Co.

59-660 Epoxy Resin–Orlon Cable Terminations for 4-Kv Service. *J. J. Rueckert, O. W. Lusby, P. L. Betz*, Baltimore Gas & Electric Co.

DP59-661 Miscellaneous Joints and Terminations Using Epoxy Resin–Orlon Insulation. *H. E. Ziegenfuss, J. J. Rueckert, O. W. Lusby, P. L. Betz*, Baltimore Gas & Electric Co.

DP59-662 Cable Sheath and Accessory Repairs Using Epoxy Resin–Orlon Tape. *T. J. Claggett, J. J. Rueckert, O. W. Lusby*, Baltimore Gas & Electric Co.

2:00 p.m. Transformers—I

J. M. Jesatko, Session Chairman
Federal Hill Room

DP* The V/g Design Applied to a 7,500-Kva 34.5-Kv Transformer. *C. Wasserman*, Baltimore Gas & Electric Co.; *J. W. Dickens*, Westinghouse Electric Corp.

DP* Sound Control for Medium Transformers. *T. J. Twomey*, General Electric Co.

DP59-663 Correlation of Free and Forced Oscillations of Coils and Windings. *P. A. Abetti*, General Electric Co.

59-664 Measurement of Ambient Air Temperature During Temperature Rise Tests on Transformers. *M. F. Beavers*, General Electric Co.

Membership in the American Institute of Electrical Engineers, including a subscription to this publication, is open to most electrical engineers. Complete information as to the membership grades, qualifications, and fees may be obtained from Mr. N. S. Hibshman, Secretary, 33 West 39th Street, New York 18, N. Y.

Thursday, May 21

9:00 a.m. Computers and Automatic Programming—II

A. L. Karpinski, Session Chairman
Fairmount Room

59-665 SPUD—A Stored Program Universal Demonstrator for Computer Training. *M. Raspanti*, Bell Telephone Laboratories

DP* A Generalized Scanner for Character and Pattern Recognition Studies. *W. H. Highleyman*, Bell Telephone Laboratories.

DP* A Radar Information Recording Device. *B. L. Harris*, Westinghouse Electric Corp.

DP* A Data Comparison and Logging System. *J. L. Russell*, Bendix Aviation Corp.

DP* Electrical Engineering Applications on Digital Computers. *Lee Garbrick*, Burroughs Corp.

9:00 a.m. Power Systems Dispatching

W. M. Hanna, Session Chairman
Founders Room

CP58-1282 New Load Dispatching Center for the Philadelphia Electric Co. System. *W. H. Johnson*, Philadelphia Electric Co.

58-1163 Automatic Dispatching Systems. *M. J. Brown*, Westinghouse Electric Corp.

DP* A Digital Computer Solution of Economic Dispatching and Interchange Billing. *F. J. Sherman, W. B. Tagen*, Boston Edison Co.

9:00 a.m. High-Voltage Bushings

M. G. Culver, Session Chairman
Federal Hill Room

59-666 Correttes Models for Obtaining Electrical Data on Insulation for Bushings. *R. D. Alvord*, General Electric Co.

DP59-640 Development of a 2,050-Kv BIL High-Voltage Bushing. *P. B. Shade*, General Electric Co.

DP59-667 Representation of Dielectric Boundaries and Cylindrical Fields on Teledeltos Field Plotting Paper. *F. D. Martzloff*, General Electric Co.

DP* Bushing Potential Device with Multiple Ratings and Universal Application. *K. W. Eissmann*, General Electric Co.

9:00 a.m. Industrial Equipment and Control—III

A. G. Hoyt, Session Chairman
Mt. Vernon Room

DP* Safety by Isolation in Industrial Motor Control. *W. G. Wilkinson, L. J. Woodward*, Rowan Controller Co.

DP59-669 The Development of a Heavy-Duty Safety Switch. *W. E. Keating*, Square D Co.

DP* Applications of Proximity Limits Switches. *G. Q. Lofgren*, Square D Co.

DP* Combination Regulator Design and Application. *R. E. Leyton*, Clark Controller

DP59-670 Characteristics of the 50 Amp Silicon Control Rectifier—A New Component for Control Applications. *R. F. Dyer*, General Electric Co.

9:00 a.m. Semiconductors and Circuits

P. F. Pittman, Session Chairman
Phoenix Room

DP* A Transistorized Power Supply for a Radar Modulator. *R. W. Sedgwick*, Bendix Aviation Corp.

DP59-671 An Investigation of the Dynamic Switching Properties of 4-Layer Diodes. *G. E. McDuffie, Jr., W. L. Chadwell*, The Catholic University of America

DP* A Pulse-Code Modulation Instantaneous Compandor. *H. M. Straube*, Bell Telephone Laboratories

DP* A Nonlinear Pulse Code Modulation Encoder. *H. Mann*, Bell Telephone Laboratories

DP59-639 Design Parameters for Weather Resistant Electrical Connectors. *L. L. Resser, M. J. Smith*, The Martin Company

9:00 a.m. Engineering Education

Dr. Frank Smith, Session Chairman
Calvert Room

DP* G. S. Brown, Massachusetts Institute of Technology

DP* Prof. G. A. Richardson, Worcester Polytechnic Institute

DP* T. M. Linville, General Electric Co.

DP* R. L. McFarlan, Raytheon Corporation

2:00 p.m. Electronic Equipment and Amplifiers

F. J. Euler, Session Chairman
Fairmount Room

DP* High-Powered Audio Applications. *R. W. Clifford, T. J. Hayes*, Westinghouse Electric Corp.

DP* Response of Band Pass Feedback Amplifiers. *L. A. Nix, Jr.*, Westinghouse Electric Corp.

DP* Magnetic Amplifier Control of an X-ray Tube. *P. A. Duffy*, Westinghouse Electric Corp.

DP* Radiation Dosage Metering in X-ray Tables. *E. L. Webb*, Westinghouse Electric Corp.

59-672 An Equivalent Circuit for Transformers in which Nonlinear Effects are Present. *H. W. Lord*, General Electric Co.

2:00 p.m. Television

W. A. MacCrehan, Session Chairman
Phoenix Room

DP* A Medium-Haul Private Microwave System for Television. *J. B. Bullock*, RCA

DP* The Application of Television at Low Light Levels. *B. A. Bang*, Bendix Friez

DP59-673 A Procedure for the Selection of Terminating Impedances of Tuned Transistor Amplifiers. *J. G. Humphrey*, General Electric Co.

DP* Video Instruction Techniques. *F. J. Beste, Jr., W. F. Jacob, Jr.*, Maryland Telecommunications, Inc.

59-674 Experience with Long-Distance Television Fields Used for Retransmission. *W. L. Braun*, WSVA, Shenandoah Broadcasting, Inc.

2:00 p.m. Rotating Machinery—II

J. L. Bennett, Session Chairman
Founders Room

DP59-675 An Approach to the Evaluation of Insulation Systems in Portable Electrical Tool Motors. *C. L. Gough, J. W. Marshall*, Black & Decker Mfg. Co.

DP* Insulation System Development Aided by Motorette Tests. *P. J. Lucey, G. T. Gibson*, Westinghouse Electric Corp.

DP* New Insulation for Cement Plant Motors. *R. B. Chappell*, Allis Chalmers Mfg. Co.

DP* An Unusual Method for Replacing a Rotar Spider in a Waterwheel Generator. *P. M. Bell*, Westinghouse Electric Corp.; *W. R. Small, Jr.*, Pennsylvania Power & Light Co.

AIEE Future Meetings

Empire District Meeting*
Hotel Syracuse
Syracuse, N. Y.
April 29-May 1, 1959

AIEE-IRE-EIA-WCEMA Joint Electronic Components Conference*
Benjamin Franklin Hotel
Philadelphia, Pa.
May 6-8, 1959

AIEE-ASME-IRE Automatic Techniques Conference*
Pick Congress Hotel
Chicago, Ill.
May 11-13, 1959

AIEE-University of Vermont Symposium on the Nuclear Power Plant
University of Vermont
Burlington, Vt.
May 14-15, 1959

Appliance Technical Conference*
Hotel Manger
Cleveland, Ohio
May 18-19, 1959

Middle Eastern District Meeting*
Lord Baltimore Hotel
Baltimore, Md.
May 19-21, 1959

AIEE-ISA-ARS-IAS National Telemetering Conference*
Brown Palace and Cosmopolitan Hotel
Denver, Colo.
May 24-27, 1959

International Conference on Information Processing
UNESCO House
Paris, France
June 15-20, 1959
(Exhibits June 13-22)

Paper and Pulp Conference*
University of Maine
Orono, Maine
June 18-19, 1959

Summer and Pacific General Meeting*
Olympic Hotel
Seattle, Wsh.
June 21-26, 1959

Air Transportation Conference*
(at Summer General Meeting)
Olympic Hotel
Seattle, Wash.
June 22-26, 1959

Petroleum Industry Conference
Wilton Hotel
Long Beach, Calif.
August 23-26, 1959
(Final date for †TP—May 25, ‡CP Syn.—June 9, CPMs—June 19)

AIEE-ASME Engineering Management Conference
Statler Hotel
Los Angeles, Calif.
September 16-18, 1959
(Final date for †TP—June 18, ‡CP Syn.—July 3, CPMs—June 13)

AIEE-IRE Nonlinear Magnetics and Magnetic Amplifiers Conference
Shoreham Hotel
Washington, D. C.
September 23-25, 1959
(Final date for †TP—June 22, ‡CP Syn.—July 10, CPMs—July 20)

AIEE-ASME National Power Conference
Muehlebach Hotel
Kansas City, Mo.
September 27-October 1, 1959
(Final date for †TP—June 29, ‡CP Syn.—July 14, CPMs—July 24)

AIEE-IRE Industrial Electronics Conference
Melon Institute
Pittsburgh, Pa.
September 30-October 1, 1959
(Final date for †TP—July 2, ‡CP Syn.—July 17, CPMs—July 27)

Fall General Meeting
Morrison Hotel
Chicago, Ill.
October 11-16, 1959
(Final date for †TP—June 12, ‡CP Syn.—July 30, CPMs—Aug. 7)

National Electronics Conference
Sherman Hotel
Chicago, Ill.
October 12-14, 1959
(Final date for †TP—July 14, ‡CP Syn.—July 28, CPMs—Aug. 7)

Fall Textile Conference
Charlotte Hotel
Charlotte, N. C.
October 15-16, 1959
(Final date for †TP—July 17 ‡Syn. —July 31, CPMs—Aug. 11)

Machine Tools Conference
Hotel Cleveland
Cleveland, Ohio
October 19-21, 1959
(Final date for †TP—July 21, ‡CP Syn.—Aug. 4, CPMs—Aug. 14)

AIEE-IRE-ISA National Automatic Control Conference
Sheraton Hotel
Dallas, Tex.
November 4-6, 1959
(Final date for summaries—June 1)

AIEE-IRE-ISA Electrical Techniques in Medicine and Biology Conference
Sheraton Hotel
Philadelphia, Pa.
November 10-12, 1959
(Final date for †TP— Aug. 12, ‡CP Syn.—Aug. 28, CPMs—Sept. 7)

Magnetism and Magnetic Materials Conference
Sheraton Cadillac Hotel
Detroit, Mich.
November 16-19, 1959
(Final date for †TP—Aug. 18, ‡CP Syn.—Sept. 1, CPMs—Sept. 11)

AIEE-IRE-ACM Eastern Joint Computer Conference
Statler Hotel
Boston, Mass.
November 30-December 3, 1959
(Final date for †TP—Sept. 1, ‡CP Syn.—Sept. 15, CPMs—Sept. 25)

AIEE-NEMA Second National Conference on Application of Electrical Insulation
Shoreham Hotel
Washington, D. C.
December 8-10, 1959
(Final date for †TP—Sept. 9, ‡CP Syn.—Sept. 25, CPMs—October 5)

Winter General Meeting
Hotel Statler
New York, N. Y.
January 31-February 5, 1960
(Final date for †TP—Nov. 2, ‡CP Syn.—Nov. 17, CPMs—Nov. 27)

AIEE-IRE-U of P Transistor and Solid-State Circuits Conference
University of Pennsylvania
Philadelphia, Pa.
February 11-12, 1960
(Final date for †TP—Nov. 12, CP Syn.—Nov. 27, CPMs—Dec. 8)

Southwest District Meeting
Shamrock-Hilton Hotel
Houston, Tex.
April 4-6, 1960
(Final date for †TP—Jan. 4, DPMs—Jan. 29)

Great Lakes District Meeting
Hotel Pfister
Milwaukee, Wis.
April 27-29, 1960
(Final date for †TP—Jan. 28, DPMs —Feb. 22)

*Final date for submitting papers—closed

†TP—Transactions Paper
‡CP Syn.—Conference Synopsis
CPMs—Conference Manuscript
DPMs—District Manuscript
(District Paper Synopses should be directed to the District Meeting Committee)

Transactions and conference papers must conform to the requirements in *Authors Guide*
For a copy, write to E. C. Day AIEE, 33 W. 39th St., New York, N. Y.

2:00 p.m. Engineering Management—II

Dr. W. C. Gore
Federal Hill Room

DP59-676 Educating Electrical Engineers for the Nuclear Age. *J. C. Michalowicz,* Catholic University of America

CP58-1211 Selection and Training of Operating Personnel for the Nuclear Power Station. *E. J. Woolever,* Shippingport Atomic Power Station, Duquesne Light Co.

CP58-1283 The Selection and Training of Operating Personnel. *N. J. Thrasher,* Long Island Lighting Co.

DP59-677 Russian Electrical Engineering Vocabulary. *Mrs. F. F. Buckland,* General Electric Co.

2:00 p.m. Power Transmission and Distribution—II

G. C. McCabe, Session Chairman
Calvert Room

DP* Baltimore Harbor Tunnel—Electrical Facilities. *W. B. Donat,* Baltimore, Md.

DP* Twenty Years' Experience with Neoprene in the Wire and Cable Industry. *C. E. McCormack,* E. I. du Pont de Nemours & Co. (Inc.)

CP58-1254 First Report on Corrosion Tests of a New Steel Wire with Thick Aluminum Coating. *J. G. Cavanagh,* Copperweld Steel Co.

DP* Spray Application of Silicone Grease to Prevent Insulator Surface Contamination. *R. H. Lester,* General Electric Co.

DP* The Teinograph—A New High-Voltage Surge Recorder. *J. G. Anderson, R. U. Giacomi,* General Electric Co.

2:00 p.m. Transformers—II

C. S. Randall, Session Chairman
Mt. Vernon Room

DP* Are Reduced Insulation Transformers Safe? *S. R. Lindgren,* Allis Chalmers Mfg. Co.

58-1169 Are Stabilizing Windings Necessary in All Y-Connected Transformers? *B. A. Cogbill,* General Electric Co.

DP* Operation of the 3-Phase Y Y Distribution Transformers under Abnormal Conditions. *G. F. Renoff, W. P. Taylor,* Baltimore Gas & Electric Co.

58-1154 Influence of Performance and Design Limits on the Design of Power Transformers by Computer. *W. G. Chambers,* Westinghouse Electric Corp.

Annual Meeting

The Annual Meeting of the American Institute of Electrical Engineers will be held in Seattle, Wash., at 2:00 p. m., Monday, June 22, 1959, during the Summer and Pacific General Meeting.

At this meeting, the annual report of the Board of Directors and the reports of the Committee of Tellers on the ballots cast for the election of officers and for the proposed amendments to the AIEE Constitution will be presented. The Lamme Medal will be presented to Philip L. Alger (AM '17, M '22, F '30) and Sterling Beckwith (AM '34, M '42, F '49).

Such other business, if any, as may properly come before the Annual Meeting may be considered.

Signed N. S. HIBSHMAN
EXECUTIVE SECRETARY

Summer and Pacific General Meeting Will Be Held in Seattle, Wash., June 21-26

THE AIEE Summer and Pacific General Meeting will be held June 21-26, 1959, in Seattle, Wash. Headquarters will be the Olympic Hotel where all technical sessions, as well as most of the social events will be held. This annual meeting commemorates a milestone in the history of the Institute since it celebrates the 75th year of its founding. The opening session will be addressed by Mayor Gordon Clinton of the City of Seattle.

The Seattle Section extends a hearty welcome to the members of the Institute to attend and is planning on a large attendance. Seattle is the center of the Pacific Northwest and the gateway to Alaska. The scenery of its surrounding mountains, lakes, and beaches makes it an ideal vacationland where those who bring their families may combine pleasure with business.

This General Meeting of the Institute will be combined with the Air Transportation Conference which is sponsored by the AIEE Air Transportation Committee. The registration desk and meeting rooms for the Summer General Meeting and the Air Transportation Conference will be at the Olympic Hotel and the hotel reservations for those attending will be handled by the Hotels Committee.

Hotel Reservations

Rooms have been set aside at 15 downtown Seattle hotels and 4 new, centrally located motels for members and guests attending the meeting. Reservations should be made as soon as possible, and must be received 2 weeks prior to the opening of the meeting. When the hotels listed are not available, the Hotel Committee chairman will forward reservation requests to another nearby hotel through the Seattle Hotel Association, which will mail confirmations directly to the members. A hotel reservation card will accompany the mailed announcements. All requests shall be addressed to the AIEE Hotel Committee Chairman, D. E. Edwards, 1015 Third Ave., Seattle 4, Wash.

The Olympic Hotel (headquarters) is convenient to all airline offices and the airport limousine.

The daily rates for rooms with private bath at the various hotels and motels are indicated in the accompanying table.

Hotels	Blocks from Headquarters	Single	Two Persons Double Bed	Two Persons Twin Beds	Suites
Olympic Hotel (Headquarters)		$8.00-$15.00	$11.00-$18.00	$14.00-$20.00	$35.00-$45.00
New Washington	6	7.00-10.00	9.00-12.00	10.50-15.00	16.00-38.00
Roosevelt	4	7.00-9.00	10.00-12.00	12.00-14.50	14.00-25.00
Mayflower	4	7.00-8.00	9.00-10.00	11.00-12.00	20.00
Hungerford	1	6.00-8.00	8.00-10.00	11.00-12.00	
Spring Apt.	1	8.50	10.50	12.50	
Earl	1	5.00	7.00	8.00-9.00	
Waldorf	4	5.00-6.00	7.00-8.00	9.00-10.00	
Windsor	1	7.00-9.00	9.00-11.00	10.00-11.00	20.00-35.00
Motels					
City Center	12	5.50-6.50	7.50-8.00	8.75-10.00	11.00-16.00
Seattle Travelodge	9	6.50-8.00	8.50-10.00	9.50-12.50	
Towne Center	7	8.78	8.78	9.82	
Towne Motel	8	8.00	9.50	10.00	

Technical Program

The Technical Operations Department has tentatively indicated there will be 79 technical sessions and over 300 technical papers. These will cover a wide variety of subjects. Local papers will accent power developments and the lumber and other heavy industries in the Northwest. There will be technical sessions at 9:00 a.m. and 2:00 p.m. each day from Monday through Friday except Monday afternoon which is reserved for the Annual Meeting of the Institute. Although there will be eight or nine technical sessions running simultaneously, the subjects have been assigned so as to avoid meetings on similar subjects being scheduled at the same time. The program includes papers on basic science, computing devices, solid-state devices, magnetic amplifiers, chemical industry, and other phases of electric power and communication industry.

Air Transportation Conference

The theme of the Air Transportation Conference, "Electricity in Space," has aroused considerable interest and produced an unusual number of papers. There will be a total of 11 technical sessions and more than 50 papers. These will include papers devoted to work done under the Air Force "Hotelec" program for development of electric equipment for use in 600 F ambient. Other papers will be devoted to magneto hydrodynamics, ion jets, and plasma jets.

An evening general-interest panel is planned for Wednesday evening. The theme of the panel discussion will be "Electrical Problems in Space." E. C. Wells, vice-president and manager, systems management office, Boeing Airplane Company, will act as moderator. Four panel members, experts in their fields, will present their views followed by discussions and questions from the audience. In addition, the committee is planning a lunch-

con with a speaker prominent in the aircraft industry.

Inspection Trips

A program of inspection trips of both technical and general interest has been arranged for those attending the meeting. Since the number of persons who may be accommodated on some of these trips is limited, members who are interested are urged to make arrangements and obtain full details at the inspection trips desk immediately after registering. In addition, some of these trips will require advance reservations, for which space will be provided on the Advance Registration Card.

An all-day trip to the Skagit River hydroelectric development of the Seattle City Lighting Department will include a 150-mile bus tour through the scenic Skagit River, Mount Baker area. A boat ride across the lake formed by the dam is part of the trip. The generating plants will be open for inspection and lunch will be served at the site.

Both forestry and milling operations will be seen during a field trip to the White River Branch of the Weyerhaeuser Timber Company. Its 120,000-acre tree farm, managed scientifically on a sustained yield basis, will keep the mill supplied with logs forever. The mill, one of the most modern and efficient in the world, produces more than 55 million board feet annually of finished lumber from douglas fir, West Coast hemlock, western red cedar, and other species.

Another inspection trip of great interest will be to the Scott Paper Company, Pulp and Paper Division, new plant at Everett. Here the visitors can see the entire process of converting the logs into all types of paper products.

Something new is being offered in inspection trips at this meeting: an air cruise, lasting 5 hours, will fly over and circle many of the major hydroelectric plants in the State, including the plants of the Seattle City Lighting Department, the Puget Sound Power & Light Company and the U. S. Bureau of Reclamation, including Grand Coulee.

The Boeing Airplane Company, builder of the 707 jet transports, will have inspection trips scheduled for their Seattle and Renton plants. Visitors will be able to observe the production of modern aircraft on the jet transport assembly line, as well as testing of advanced aircraft and the operation of the wind tunnel.

Social Events

Carrying on tradition, an informal tea will be held on Sunday afternoon, June 21, at the Olympic Hotel. This social gathering has been enjoyed at other meetings by more and more people each year. This tea will offer the opportunity to greet old friends informally before the hustle and bustle of the meeting.

The highlight of the social activities will be the one-hour boat cruise across Puget Sound to beautiful Agate Pass for a salmon barbecue, characteristic of this part of the country. Those attending will enjoy the boat trip in the afternoon to the park where barbecuing will have been under way for several hours. An Indian ceremony is planned at Kiana Lodge. Three large boats have been reserved for this trip, which will be on Thursday.

There will be general luncheons on Tuesday and Wednesday, the speakers and subjects of which will be announced later.

Ladies Entertainment

A full and varied program of ladies activities is being planned. On Tuesday there will be a tea and talk on colors by a noted authority and analyst. The theme will be "What Is Your Personal Color Scheme." A demonstration of various individual's co-ordinated color schemes will be part of the program.

On Wednesday, there will be a guided sight-seeing tour of the city, including a tea at the Seattle Art Museum.

On Thursday, there will be a champagne luncheon and fashion show. On Friday, there will be brunch and flower arrangement talk by one of Seattle's leading florists and an outstanding artist in that field. Plans have been made for small garden tours and individual sight-seeing.

Sports

Arrangements have been made for guests of the Institute to crew on the regular Wednesday afternoon Senior Knockabout Club sailboat races. One AIEE crew man will be assigned to each boat. Golfing also will be available.

There will be a fishing trip on chartered boats at Westport on Saturday morning. The boats sail early in the morning so it will be necessary for those going fishing to leave Seattle Friday evening. Westport is one of the best salmon fishing areas on the West Coast and fishermen can usually catch a 10- or 20-pound fish per trip.

Post-Convention Trips

A post-convention air cruise to Hawaii is available. This all-expense tour leaves Seattle Friday night, June 26, and returns to any major West Coast city on July 5. Included is round trip air transportation from Seattle to Honolulu and return to Seattle, Portland, San Francisco, or Los Angeles, via Pan American Airways. Also included is air transportation on an outer island trip, sight-seeing, meals, hotels, and ground transportation. Address all correspondence for reservations to Banker's and Merchant's Travel Service, 511 Fifth Ave., New York 17, N. Y. The total cost is $487, plus $8.73 tax, per person. A deposit of $50 should accompany the reservation application and the balance is due June 1.

Persons planning other post-convention trips can secure complete information upon request from the Tourist and Convention Bureau of the Seattle Chamber of Commerce at 215 Columbia St. Seattle 4, Wash.

Electrical Engineering

75th Anniversary Issue Available

A limited number of hardbound, silvercloth copies of the May 1959 issue of *Electrical Engineering* commemorating the 75th Anniversary of the Institute are available at $2.50 per copy. Those interested in obtaining a copy are asked to fill in and return the coupon below before July 1, 1959. Please enclose remittance.

To AIEE, 33 West 39th Street, New York 18, N.Y.

This is an order for one hardbound, silvercloth copy of the May 1959 issue of ELECTRICAL ENGINEERING

Name _____
(type or print)

Address _____

Remittance enclosed $ _____

TO EXPEDITE DELIVERY PLEASE COMPLETE MAILING LABEL BELOW

Name _____
(type or print)

Address _____

Postmaster: This parcel may be opened for Postal Inspection if necessary. Return postage guaranteed.

(Contents—Printed Matter) Printed in U. S. A.

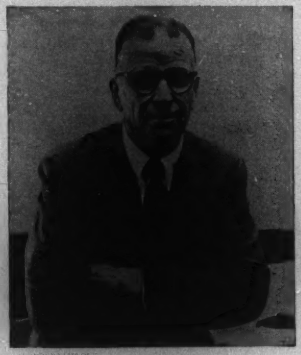
A Message to All Members of the Engineering Societies Co-operating in the United Engineering Center

M. J. KELLY, General Chairman
Industrial Building Fund Committee
United Engineering Center

WE ARE IN THE MIDST of the campaign for funds for the construction of the new Engineering Center—the headquarters of 10 Societies. If the Societies are to meet their obligations of today and the challenges of tomorrow, the new Center must be provided.

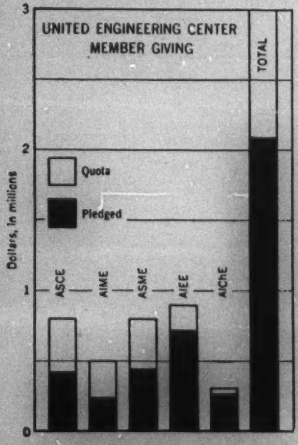
The threat that now faces our society and, in fact, all free peoples is the tragedy of our times. The USSR's often-stated purpose of communizing the world with the utilization of her rapidly increasing military and economic strengths to attain this goal is the threat we face. It can only be countered by equal or greater strengths in our Nation and the associated free societies. These strengths are determined by the scientific and technologic development of our Nation and associates.

To counter this threat, our Nation's scientific and technologic capacities must be developed to the highest possible level, only limited by the inherent capacities of our people. The Societies make large contributions to the Nation's technologic strength through the many services they render to engineers. They provide a professional framework for engineers. They provide publications, meetings, and forums for presenting information on technologic progress. They aid in the development of young engineers through establishing standards for engineering education, through student branch activities,



and through the impact of their publications on engineering curricula.

The present Center—now more than 50 years old—is wholly inadequate; it is limiting the effectiveness of the Societies. The new Center is essential. Its location across from the United Nations is an ideal setting, typifying the Societies' national and international importance. The building, while strictly functional, has an impressive dignity and a necessary large size that give striking evidence of the magnitude of the Societies's activities.



THE BAR GRAPH shows the status of member giving as of March 13, 1959. All contributions to the UET Building Fund are tax deductible.

Progress of the Funds Campaign

In late 1957, based on an estimated cost of $10 million for building and land, a quota of $5 million was established for the Nation's industries and $3 million for members of the Societies. The value of present building and site was appraised at $2 million. Industry's campaign began under my leadership in November 1957. The membership campaign began some six months later. At mid-February, some $4 million had been subscribed by industry and $2 million by members of the Societies. Splendid progress has been made.

We must not only meet our goals of $5 and $3 million respectively, we must exceed them. Building costs have advanced since the 1957 estimate and the site cost was greater than anticipated. There is adequate potential both from industry and from Societies' membership for our going well beyond the goals—adequate to cover complete cost of building and site.

The industry solicitors are proceeding with renewed zeal in their solicitation of all industry that employs engineers who are members of the Societies. As a clean-up, beginning in June of this year, I shall personally resolicit the chief executive of each company that has not subscribed whose company has a gift potential of $5,000 or more.

In the membership campaign, 40,000 members have subscribed $2 million. Certainly it is not too much to anticipate another $2 million from the remaining 140,000 members.

I consider it an opportunity, a duty, and a solemn obligation for each member of the Societies to participate in funding the new Center. Let us strive for a 100% participation!

General Contractor Named for United Engineering Center

Turner Construction Company of New York has been named as the general contractor for the United Engineering Center. This new headquarters of the Nation's leading engineering societies will be erected on the west side of United Nations Plaza between 47th and 48th Streets in New York City.

The anouncement was made by Andrew Fletcher, president of United Engineering Trustees, Inc., and president of St. Joseph Lead Company of New York.

Bimonthly Publications

The bimonthly publications, *Communication and Electronics, Applications and Industry*, and *Power Apparatus and Systems* contain the formally reviewed and approved numbered papers presented at General and District meetings and conferences. The publications are on an annual subscription basis. Members may receive one subscription to any *one* of the bimonthlies for $2.50. The balance of the annual $5.00 subscription price will be paid by application of his annual dues for the year of the subscription. (Members may not reduce the amount of their dues payment by reason of nonsubscription.) Additional member subscriptions will be at the rate of $5.00. Nonmembers may subscribe on an advance annual subscription basis of $8.00 each (plus 50¢ extra for foreign postage payable in advance in New York exchange). Single copies, when available, are $1.50 each. Discounts are allowed to libraries, publishers, and subscription agencies.

NIFE SALUTES THE A.I.E.E.
ON THEIR 75TH ANNIVERSARY

NIFE
REG. U. S. PAT. OFF.

The Original NICKEL CADMIUM BATTERY

WHO

RAILROADS: Engine Starting, Caboose Power, Communications, and Signaling — POWER STATIONS: Switchgear and Emergency Power — COMMUNICATION SYSTEMS: Standby Power — Marine: Engine Starting, Emergency Lighting, Radio and Alarm — PUBLIC BUILDINGS: Emergency Lighting — FIRE ALARM: Emergency Power.

WHY

Because: Nife Batteries are easily maintained; Nife Batteries have exceptionally long life; Nife Batteries are not damaged by over charge, deep cycles, low floating charge; Nife Batteries have low self discharge and may be stored for long periods of time without special care; Nife Batteries' state of charge may be determined by the use of a reliable voltmeter and ammeter during charge.

WHEN

In an emergency Nife Batteries have sure dependable power. They give thousands of cycles of charge and discharge. They are immune to such abuses as overcharge, undercharge, short circuits, heavy cycling — even reverse charge, shock, and vibration. Sub-zero temperatures and Excessive Heat will cause no damage.

WHERE

Switchgear Tripping and Closing: High discharge current for fractions of a second — Engine Cranking: Marine, Stationary and Locomotive Engine starting requires high breakaway and rolling current — Communications and Signaling: A reliable source of power for peak loads and emergencies — Emergency Power and Supervisory Control: A dependable battery immune to abuses and free from plate buckling, sulphation, and shedding — Mobile Equipment: A sure power battery resistant to shock and vibrations.

IN WORLDWIDE SERVICE FOR FIFTY YEARS

NICKEL CADMIUM BATTERY DIVISION OF

NIFE INCORPORATED

COPIAGUE, L. I. • NEW YORK, U. S. A.

WRITE FOR COMPLETE INFORMATION

For more information circle 12 on reader service card.

"New Products" of 1934-59 . . .

Some of the more significant developments of the past 25 years.

Clock Radio . . . (1934)

Once set, this Time-o-Matic receiver provides any combination of programs desired. After turning itself off at night, it will go on again in the morning and serve as an alarm clock. Although the mechanism is described as a complicated problem in radio engineering, the operation is simple. A series of small holes around the clock's face mark the quarter-hour periods and serve as connecting channels between the time-clock arrangement and tuning mechanism which has 16 outlets in the form of miniature telephone switchboard cords, two to each of seven stations and providing for 14 different program periods, with two extra cords for intermission periods. **A. Atwater Kent.**

Automatic Steering Control . . . (1934)

Drift caused by wind has been one of the major difficulties encountered in developing automatic steering apparatus for airplanes. With this completely automatic system still in the experimental stage, radio signals can be used to correct for wind drift. Three forms of automatic steering will be made available: (1) magnetic-compass, (2) radio compass, and (3) automatic drift correction by radio. The effective range of this control equipment is 150 miles and it is not yet completely developed. **General Electric Co.**

Two-way Radio Communications . . . (1934)

Developed for the Boston Police Department, this mobile two-way radio is the first practical system which enables officers in prowl cars to converse freely with precincts and headquarters while actually cruising their districts. A French-type telephone is located conveniently on the instrument panel and functions immediately when lifted from its hook. The transmitter has a power of 15 watts and operates on the ultrahigh frequency corresponding to a wavelength of 8 meters. **General Electric Co.**

Diesel-Electric Train . . . (1934)

A new age in railway passenger transportation was ushered in with the christening of the Zephyr, a 3-car, articulated, streamlined, stainless-steel high-speed train. Built for the Chicago, Burlington and Quincy, the unit is powered by a Winton 600-hp Diesel-electric power plant designed to drive the train at speeds of 110 mph. The Zephyr will make an extensive tour of the country prior to its being placed on exhibition at the Century of Progress in Chicago. **Edward G. Budd Manufacturing Co.**

Television over Coaxial Cable . . . (1936)

With the official opening of the Empire State Building transmitter, both television and the coaxial cable have taken their first step in moving out of the laboratory and into the final stages prior to acceptance as commercial realities. In the RCA Building is a complete television studio for relaying "live" talent, a projection room for transmitting films, various

monitoring facilities, central synchronous generators, video line amplifiers, and other equipment. The transmitter, situated on the 85th floor of the Empire State Building 1.5 miles away, is linked to the RCA studio by uhf directional beam transmitter and the experimental coaxial cable. **Radio Corp. of America; American Telephone & Telegraph Co.**

Automatic Clothes Washer . . . (1937)

This machine will wash 9 pounds of clothes automatically from start to finish by merely adjusting two control knobs, one for water temperature, the other for washing time. The appliance soaks, agitates, washes, rinses, spins damp dry, and then shuts itself off without attention. This marks a new concept in applying cycle automation to a major appliance. **Bendix Home Appliances, Inc.**

Tape Recorder . . . (1937)

Designed to record broadcast programs in "newsreel" fashion, this instrument can store special events magnetically on a steel tape that winds off one reel and onto another. When the tape is "played back," the magnetic variations in the tape produce minute electrical currents in a pick-up coil which are amplified and passed on to the broadcast transmitter. Over-all dimensions of the recorder are approximately 5 feet wide, 4 feet high and 2 feet deep. **Marconi-Stille Recording Machine.**

Low-Pressure Gas-Filled Cable . . . (1938)

The first trial installation of a 15-kv low-pressure gas-filled cable was installed in the Yonkers Electric Light and Power Co. Consisting of a single 3-conductor cable circuit 10,000 feet in length, a single copper-bearing lead sheath was applied in an atmosphere of nitrogen after the cable had been dried, impregnated, and drained of surplus compound. After leading, the ends were sealed and the lengths shipped and pulled into ducts. The average working pressure will be between 8 and 15 pounds per square inch. **General Electric Co.**

Fluorescent Lamp . . . (1938)

Efficient fluorescent powders, coupled with an increased knowledge of hot cathodes and progress in the production of short-wave ultraviolet radiation, have resulted in the development of this new, highly efficient tubular lamp. Small tungsten wires at each end serve as emissive electrodes. Argon gas facilitates starting

and a small drop of mercury provides the discharge vapor. Activated by ultraviolet light generated by the mercury, the powder-coated sides reradiate this energy into visible light. A 15-watt "daylight" type fluorescent lamp will provide as much brilliance as a 150-watt filament type bulb. **General Electric Co.**

Million-Volt Medical X Ray . . . (1939)

This million-volt X ray, capable of penetrating a 5-inch steel casting, was in-

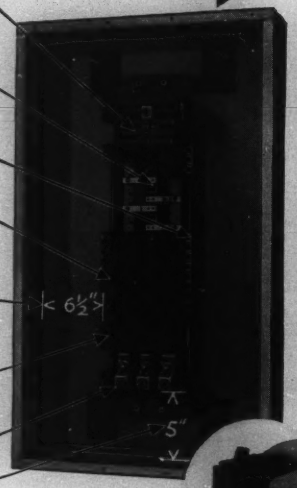
(Continued on page 20A)

YOU ARE LOOKING AT THE GREATEST IMPROVEMENT IN PANELBOARDS IN MORE THAN 20 YEARS!

This is what you've been using

This is what Square D's New NQOB Gives You*

Binder-head Screw Neutral Taps	Box-type Neutral Lugs
Large Number of Parts Required for Additions and Replacements	Simplified Breaker Connection— One Screw All Joints Plated Bussing Like Wiring Diagram You Can See What Phase You're Connected To
Screw Terminals on Branch Circuit Breakers	Box Lugs on All Circuit Breakers
Unable to Mount One and Two Pole Breakers Opposite Three Poles	One and Two Pole Breaker May Mount Opposite Three Poles
Cramped Side Gutters	20"-wide Box Provides Roomy Side Gutters and Plenty of Room for Conduit in End Wall
Special Installation Required for 100 Amp Frame Breakers	100 Amp Frame Breaker May Replace Two 50 Amp Frame Breakers
Lugs for Copper Conductors Only	Lugs for Either Copper or Aluminum UL Approved
Minimum End Gutters	Full 5" End Gutters



Write for the complete story Square D Company, 6060 Rivard Street, Detroit 11, Michigan

SQUARE D COMPANY

* The QO in NQOB means QWIK-OPEN breakers—they trip instantly at 10 times full load rating. The B in NQOB means BOLTED CONNECTIONS. If you prefer plug-in construction, specify NQO

For more information circle 13 on reader service card.

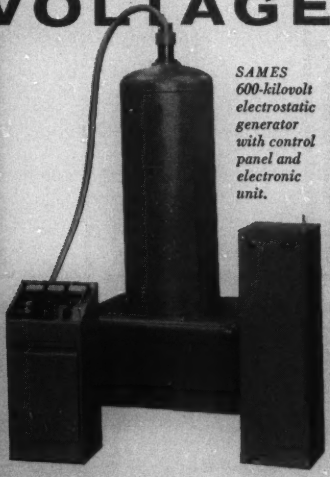
..first electrostatic generators for industrial use that can give several kilowatts at up to 600,000 volts dc

The complete line of "Sames" electrostatic generators—the first practical industrial electrostatic power supplies—are now available in the U.S. from Sorensen & Company. They supply from 50 to 600 kilovolts dc at substantial amounts of power (2400 watts for the 600 kv model).

The Sames generators (so-called from their manufacturer, Societe Anonyme de Machines Electrostatiques, Grenoble, France) are extremely compact and safe compared to transformer-rectifier-filter-type supplies in similar kilovolt ranges. The electrostatic generators are available in highly stabilized models supplying 50, 100, 150 and 600 kilovolts that are particularly suitable for electron-microscopy and many critical nuclear physics applications. Medium stability models with outputs of 50, 80, 100, 140, 150, 250, 300, and 600 kilovolts, have found wide application in Europe for testing cable insulation, alternator windings and other dielectrics, electrostatic flocking, painting and particle precipitation, electron and nuclear particle accelerators and similar applications.

Write for complete details on Sames electrostatic generators to Sorensen & Company, Richards Avenue, South Norwalk, Conn. s.3e

VOLTAGE



SAMES 600-kilovolt electrostatic generator with control panel and electronic unit.

SORENSEN & COMPANY, INC.
Richards Avenue, South Norwalk, Conn.

WIDEST LINE OF CONTROLLED-POWER EQUIPMENT FOR RESEARCH AND INDUSTRY

In Europe, contact Sorensen-Ardag, Zurich, Switzerland. In Western Canada, ARVA. In Eastern Canada, Bayly Engineering, Ltd. In Mexico, Electro Labs, S.A., Mexico City.

For more information circle 14 on reader service card.

New Products, 1934-59

(Continued from page 18A)

stalled in the Memorial Hospital, New York, N.Y., for the treatment of cancer. A great saving in weight and size over previous high-voltage equipment is the result of a tuned transformer that contains no iron core, and the X-ray tube which passes directly through the center of the cylindrical structure. **General Electric X-Ray Corp.**

FM Broadcasting System . . . (1939)

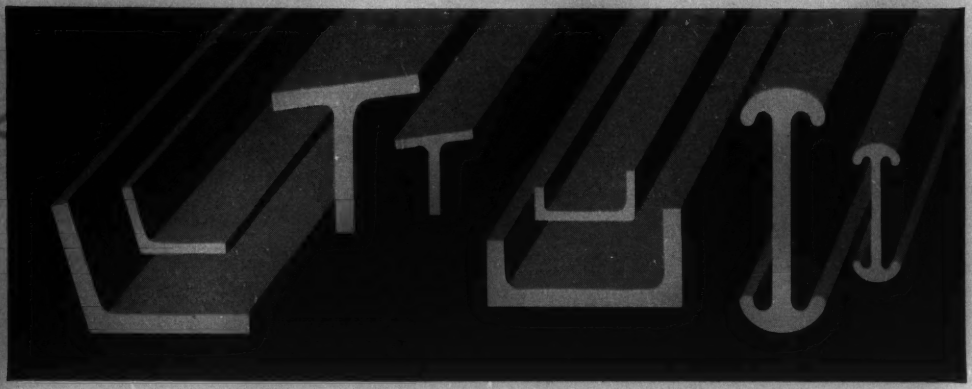
With the opening of station W2XMN in Alpine, N. J., a new method of radio broadcasting was introduced to the public. Known as frequency modulation, in contrast to amplitude modulation currently in use, this system promises new dimensions in listening pleasure. Not only will this method provide clear, static-free reception, but it will also allow for the first time the transmission and reception of high-fidelity radio programs in the full 15,000 cycle range. **E. H. Armstrong.**

Electron Microscope . . . (1941)

What was once a complicated laboratory device to be operated solely by a physicist or highly skilled technician has now become an instrument that can be operated by any competent laboratory worker. Although the first principles of the electron microscope were laid down in 1924, this year marks the first time these

instruments will be made available on a commercial basis to science and industry. This year also marks the first time man has been able to see the virus, a long step in the cure and eradication of infantile paralysis, influenza, and the common cold. **Radio Corp. of America.**

(Continued on page 24A)



BUS BAR (OR PLAIN BUS BAR)

from Reynolds

Here's a double story: design versatility plus silver plated bus bar economy. You can choose from Reynolds wide range of standard extruded bus bar shapes and sizes to meet a specific installation need without specifying oversize conductors because of intermediate size limitations. In addition, Reynolds can extrude special shapes and sizes in practically unlimited range to meet your most exacting requirements. This versatility permits designing to the minimum amount of metal needed for the current carrying job. The result is material costs lower than any other bus conductor.

And with Reynolds Silver Plated Bus Bar, you get a surface that permits higher operating temperature with bolted joints; simplified soldering. Silver plated bar also offers savings of 35 to 50% over bare or plated copper conductors. Thus you get optimum strength, high conductivity, simplified installations, design freedom—all at low cost.

Many extruded shapes because of sharp corners and shadow areas are not readily adaptable to a high quality silver plating. Such sections are subject to special inquiry.

REYNOLDS ALUMINUM

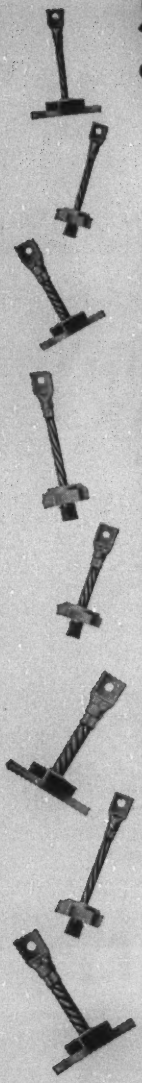
Watch Reynolds TV show—"WALT DISNEY PRESENTS"—every week on ABC-TV

For details and availability data, write today for the new brochure, "Reynolds Silver Plated Aluminum Bus Conductors", *Reynolds Metals Company, P. O. Box 2346-ER, Richmond 18, Virginia.* For assistance from Reynolds Engineering Service call your nearest Reynolds office or write to the above address.

For more information circle 16 on reader service card.

Tarzian

HIGH CURRENT SILICON RECTIFIERS



- **Extremely Compact Design**
- **Positive or Negative Base Polarity**
- **Flush or Stud Mounting**
- **Vibration Proof Construction**
- **Low Cost**

The extremely compact Flatline series of Tarzian Silicon Rectifiers features flush or stud mounting in either positive or negative base polarity. Special junction structure provides reliable operation in the most rugged applications.

20 to 200 Amps. — 50 to 400 P.I.V.

AMPERES D.C. (100° C)	PEAK INVERSE VOLTAGE	TARZIAN FLATLINE TYPE	MAX. RMS VOLTS	MAX. RECURRENT PEAK AMPERES (100° C)	MAX. SURGE AMPERES 4MS
20	50	5RAN*	35	120	200
	100	10RAN	70	120	200
	200	20RAN	140	120	200
	300	30RAN	210	120	200
	50	5RAP**	35	120	200
	100	10RAP	70	120	200
	200	20RAP	140	120	200
	300	30RAP	210	120	200
35	50	5SAN	35	210	350
	100	10SAN	70	210	350
	200	20SAN	140	210	350
	300	30SAN	210	210	350
	50	5SAP	35	210	350
	100	10SAP	70	210	350
	200	20SAP	140	210	350
	300	30SAP	210	210	350
	50	5S3N	35	210	350
	100	10S3N	70	210	350
	200	20S3N	140	210	350
	300	30S3N	210	210	350
	400	40S3N	280	210	350
	50	5S3P	35	210	350
	100	10S3P	70	210	350
	200	20S3P	140	210	350
	300	30S3P	210	210	350
	400	40S3P	280	210	350
100	50	5VAN	35	600	1000
	100	10VAN	70	600	1000
	200	20VAN	140	600	1000
	300	30VAN	210	600	1000
	50	5VAP	35	600	1000
	100	10VAP	70	600	1000
	200	20VAP	140	600	1000
	300	30VAP	210	600	1000
	50	5V3N	35	600	1000
	100	10V3N	70	600	1000
	200	20V3N	140	600	1000
	300	30V3N	210	600	1000
	400	40V3N	280	600	1000
	50	5V3P	35	600	1000
	100	10V3P	70	600	1000
	200	20V3P	140	600	1000
	300	30V3P	210	600	1000
	400	40V3P	280	600	1000

AMPERES D.C. (100° C)	PEAK INVERSE VOLTAGE	TARZIAN FLATLINE TYPE	MAX. RMS VOLTS	MAX. RECURRENT PEAK AMPERES (100° C)	MAX. SURGE AMPERES 4MS
150	50	5WAN*	35	900	1500
	100	10WAN	70	900	1500
	200	20WAN	140	900	1500
	300	30WAN	210	900	1500
	50	5WAP**	35	900	1500
	100	10WAP	70	900	1500
	200	20WAP	140	900	1500
	300	30WAP	210	900	1500
	50	5W3N	35	900	1500
	100	10W3N	70	900	1500
	200	20W3N	140	900	1500
	300	30W3N	210	900	1500
	400	40W3N	280	900	1500
	50	5W3P	35	900	1500
	100	10W3P	70	900	1500
	200	20W3P	140	900	1500
	300	30W3P	210	900	1500
	400	40W3P	280	900	1500
200	50	5XAN	35	1200	2000
	100	10XAN	70	1200	2000
	200	20XAN	140	1200	2000
	300	30XAN	210	1200	2000
	50	5XAP	35	1200	2000
	100	10XAP	70	1200	2000
	200	20XAP	140	1200	2000
	300	30XAP	210	1200	2000
	50	5X3N	35	1200	2000
	100	10X3N	70	1200	2000
	200	20X3N	140	1200	2000
	300	30X3N	210	1200	2000
	400	40X3N	280	1200	2000
	50	5X3P	35	1200	2000
	100	10X3P	70	1200	2000
	200	20X3P	140	1200	2000
	300	30X3P	210	1200	2000
	400	40X3P	280	1200	2000

*N in type number indicates negative base.
**P in type number indicates positive base.

WRITE FOR COMPLETE INFORMATION

SARKES TARZIAN, INC., Rectifier Division

DEPT. E-2, 415 NORTH COLLEGE AVE., BLOOMINGTON, INDIANA

In Canada: 700 Weston Rd., Toronto 9, Tel. Roger 2-7535 • Export: Ad Auriema, Inc., New York City

For more information circle 17 on reader service card.

(Continued from page 20A)

Mass Production of Magnetrons . . . (1942)

High-frequency magnetrons, the key component of all combat radar systems, are now being mass produced in large quantities for the first time. Stamped laminations in place of precision machining is the answer. Where formerly the anode

block, with its intricate configuration of identical keyholes and slot openings had to be carved from a solid piece of copper, this unit is now built up from laminated cross sections that have been stamped out, stacked, and then silver-soldered to form one piece. **Raytheon Mfg. Co.**

Long-Range Navigation Aid . . . (1942)

A new radio navigation aid called Loran promises to become one of the greatest advances yet made in the art of determining the exact position of a ship or aircraft at any time of the day or night and in any kind of weather. In principle, the system depends upon the measurement of the differences in time required for the same pulsed signal to reach an object from two dual operating stations. This difference in time is expressed on a chart as a series of hyperbolic or Loran lines of varying distances from the dual operating stations. The point where two hyperbolic Loran lines meet, produced by another set of dual operating stations, provides the ship or plane with an exact fix by presenting this information visually on a cathode ray tube and then transferring these coordinates to a chart showing all Loran lines for the area. **Radiation Laboratory, Massachusetts Institute of Technology.**

Polyethylene . . . (1943)

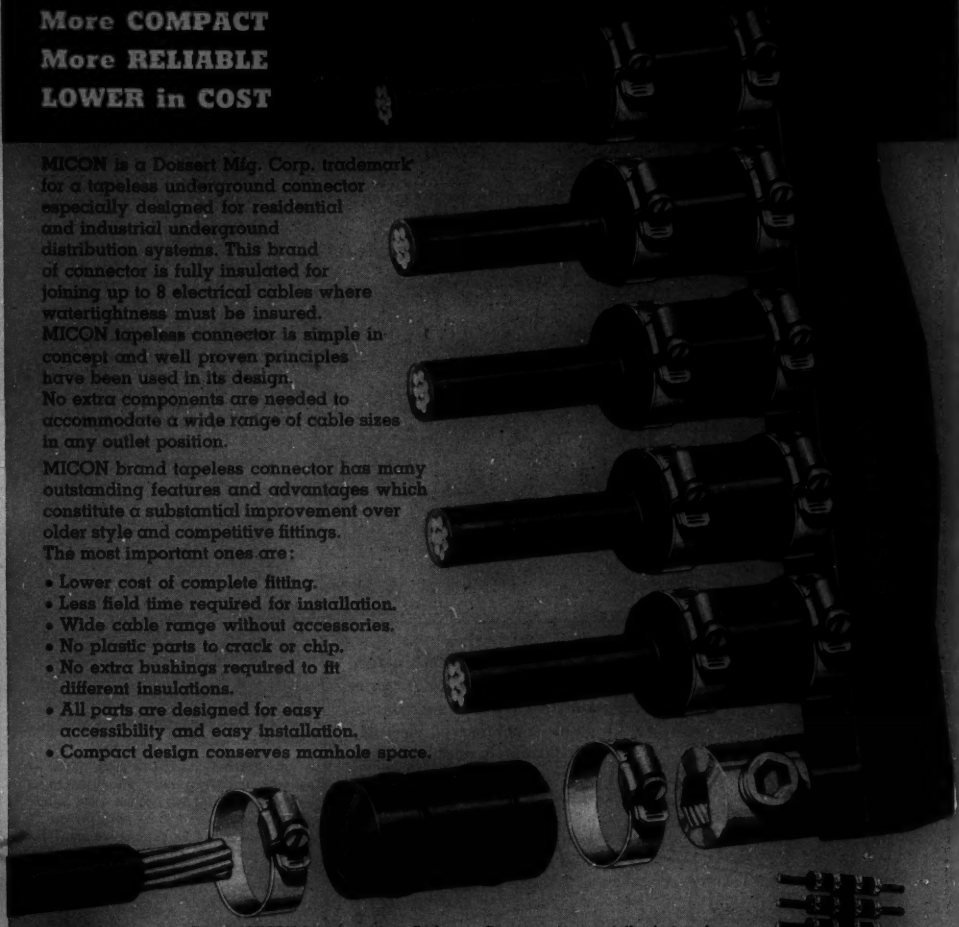
Because of its superior dielectric characteristic this product, first described in a British patent in 1937, promises to find wide application in the electrical industry. It is a white, waxy, translucent, tough, flexible substance that can be extruded, molded, formed into sheets, heat sealed, welded, cemented, machined, and polished. At the present time, polyethylene is being used principally for high-frequency cables

(Continued on page 34A)

DOSSERT MICON*

(Tapeless Underground Connector)

More COMPACT
More RELIABLE
LOWER in COST



MICON is a Dossert Mfg. Corp. trademark for a tapeless underground connector especially designed for residential and industrial underground distribution systems. This brand of connector is fully insulated for joining up to 8 electrical cables where watertightness must be insured. MICON tapeless connector is simple in concept and well proven principles have been used in its design. No extra components are needed to accommodate a wide range of cable sizes in any outlet position.

MICON brand tapeless connector has many outstanding features and advantages which constitute a substantial improvement over older style and competitive fittings. The most important ones are:

- Lower cost of complete fitting.
- Less field time required for installation.
- Wide cable range without accessories.
- No plastic parts to crack or chip.
- No extra bushings required to fit different insulations.
- All parts are designed for easy accessibility and easy installation.
- Compact design conserves manhole space.

Dossert MICON brand tapeless Crab-type Connector is especially designed for joining up to 12 electrical cables. This connector is an original Dossert design and adheres to the same principle as the tapeless type. Write for special catalog.

Request also complete UNDERGROUND CATALOG UG 53-1

*Pat. Pend. Reg. Trade Mark applied for

50

DOSSERT MFG. CORP.

249 Huron Street, Brooklyn, New York

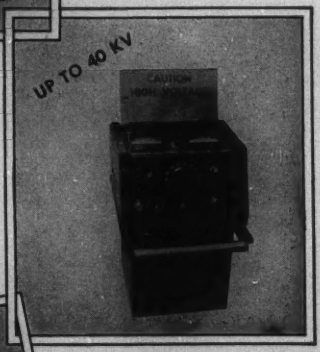
For more information circle 24 on reader service card.

DIELECTRIC TEST EQUIPMENT by BIDDLE

...for d-c tests at voltages up to 100 KV

IMPORTANT FEATURES

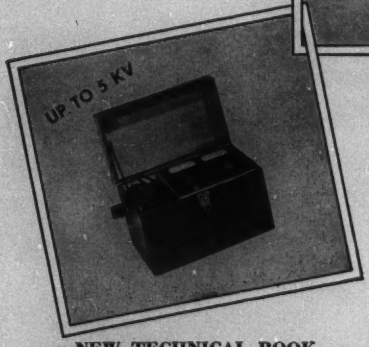
- Well-designed provisions for utmost safety
- Simple operation and reliable performance
- Excellent output voltage regulation
- Compact, mobile design
- Facilities for voltage and leakage current measurements



IMPORTANT USES

Development—to test d-c dielectric strength of insulating materials and the adequacy of the electric design of insulation in equipment.

Production—for non-destructively detecting defects in electrical insulation.

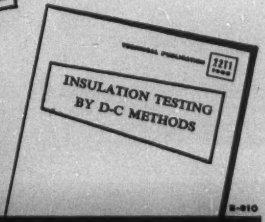


Maintenance—and preventive maintenance—for non-destructively detecting unreliable condition of electrical insulation in new or repaired equipment.

NEW TECHNICAL BOOK

A new technical treatise by E. B. Curdts, Director of Engineering, James G. Biddle Co., contains a wealth of pertinent data for the engineer interested in insulation maintenance of electrical equipment.

Copies are available at $2.00 each. Orders should be made on your company's letterhead accompanied by check to the order of the James G. Biddle Co. Ask for Publication 22T1EE.



JAMES G. BIDDLE CO.

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ELECTRICAL TESTING INSTRUMENTS • SPEED MEASURING INSTRUMENTS

LABORATORY & SCIENTIFIC EQUIPMENT

For more information circle 25 on reader service card.

New Products, 1934-59

(Continued from page 24A)

where its low losses and general physical and chemical properties are unequalled by any other material. **Carbide & Carbon Chemicals Co.**

Stereo-Color Television Tubes . . . (1944)

Colored stereoscopic images that appear directly upon the screen of the cathode-ray tube can now be achieved without the use of revolving scanning discs, mirrors, or other moving parts. Called the Telechrome, this tube differs from the conventional black and white cathode-ray tube by having two electron beams and a transparent double-sided screen. One beam produces a blue-green picture on the back surface. To the viewer, the two blend to form a color picture or a stereoscopic image when appropriate colored lens glasses are used. **John L. Baird.**

Automatic Sequence Controlled Calculator . . . (1944)

The desire to economize time and effort in arithmetical calculations, and the desire to eliminate human error have brought about the construction of this fully automatic sequence controlled calculator that tells itself what to do and

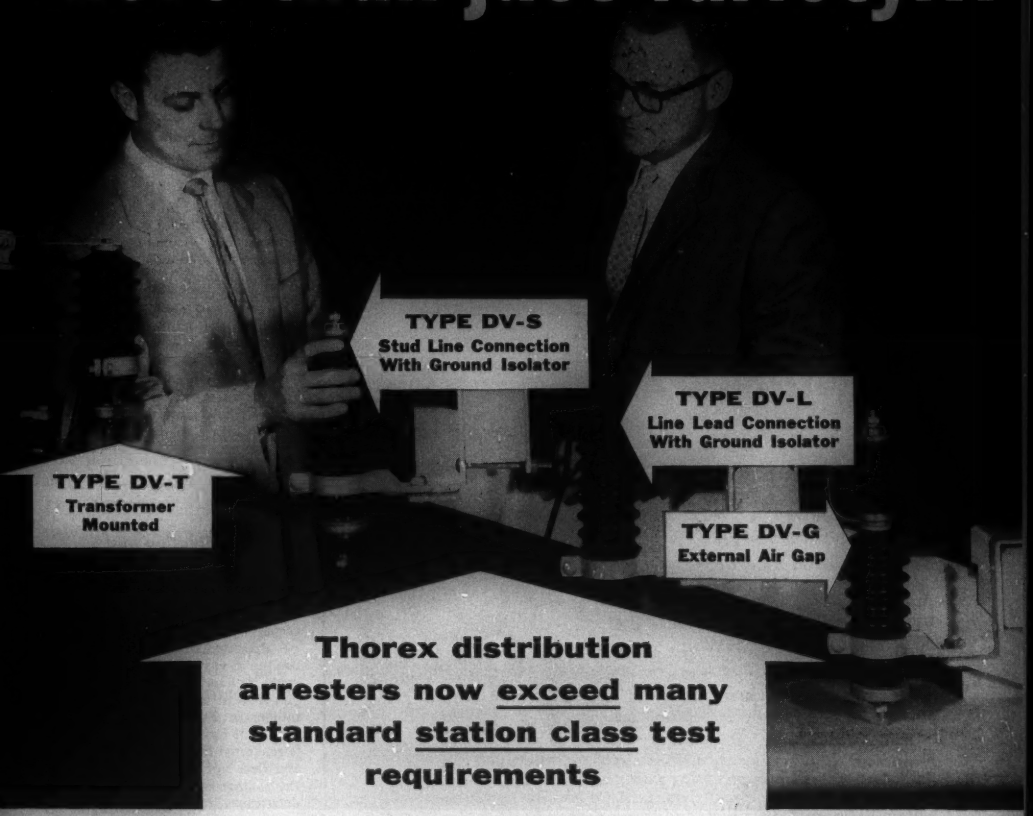
when to do it. Started in 1939, the finished machine was formally presented to Harvard University in August 1944 where it was immediately put to work for the U. S. Navy Bureau of Ships to solve many problems relating to branches of physics and engineering. **International Business Machines Corp.**

Silicone Insulation . . . (1944)

Not only will this insulation allow the design of much smaller motors for equal horsepower output, but it will permit many other types of electric power equipment to operate at much higher ambient temperatures over a longer life span without failure. For example, a 3-hp totally enclosed induction motor was redesigned for a 10-hp output with no increase in size or weight. A 250-kva generator with sili-

(Continued on page 36A)

More than just variety...



Thorex distribution arresters now exceed many standard station class test requirements

Thorex distribution arresters go far beyond just meeting your preference with their variety of designs. These remarkably efficient protective devices exceed, by a wide margin, many present Standard test requirements of the heaviest duty Station Class. And all of this in a poletop arrester 10 to 50 per cent smaller than comparable models.

Possibly this best evaluates the remarkable advancement in the arrester art represented by the Dynagap. This same protective element is interchangeable in all Thorex ratings and classes - - hence the unheard-of performance of distribution grades.

For a degree of service and equipment protection totally new in distribution practice, at no cost premium, put Thorex Dynagap Type DV arresters on your system.

OHIO BRASS COMPANY, MANSFIELD, OHIO

Ohio Brass HOLAN

PORCELAIN INSULATORS • LINE HARDWARE • CAPACITORS • LIGHTNING ARRESTERS
BUSHINGS • HOLAN TRUCK-MOUNTED POWER DEVICES AND BODIES • BRONZE VALVES

4922-H4

always awake at the switch

Amp-trap

You can count on *Amp-trap** . . . when you want to stop a 500,000 Ampere short circuit dead in its tracks. In fact, if *Amp-trap* is watching and waiting at your entrance switches or in your circuit breakers — you couldn't be safer. That's why those who know *insist on and get Amp-trap.*

**Protected for your protection by 27 patents.*

Amp-trap is *"always awake at the switch"* . . . where current limitation with high interrupting rating is required . . . on general power circuits, on DC circuits, on standard and the new higher voltage networks, on busways and entrance switches, even on general electronic circuits.

Amp-trap is a true current limiter because it anticipates and stops dangerous short circuits long before they can become destructive. Nothing takes the place of *Amp-trap.* There's one for every purpose. Ask for Bulletin 514-9.

®*Amp-trap* is a registered trademark of The Chase-Shawmut Co. and refers to a current limiting fuse and herein is written *Amp-trap.*

Amp-trap®

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REGISTERED UNITED STATES PATENT OFFICE Est. 1893

Amp-trap® — Always At The Switch

THE CHASE-SHAWMUT CO.

374 MERRIMAC STREET • NEWBURYPORT, MASSACHUSETTS

Subsidiary of I-T-E CIRCUIT BREAKER CO., Philadelphia, Pennsylvania

Amp-trap® Tri-onic® Dual-ed® C-O-T® TRIONET® and O-T fuse

For more information circle 28 on reader service card.

(Continued from page 34A)

cone insulation was operated in the laboratory for 3,000 hours at 250 F with no ill effects to the insulation. **Westinghouse Electric & Manufacturing Co.**

New Pulse Time Modulation System . . . (1945)

An experimental radiotelephone circuit using pulse time modulation has been placed in operation over an 80-mile relay circuit. This system permits 24 two-way conversations to take place at the same time on a single uhf carrier wave. A new cathode-ray tube called the cyclophone provides the electronic switching needed to develop the 8,000 pulses per second which are of constant amplitude and are all on the same carrier frequency. Modulation is produced by transmitting a synchronizing marker pulse followed by signal pulses at intervals varied at a rate corresponding to the audio frequency of the signal. **International Telephone & Telegraph Corp.**

Electronic Heating and Cooking . . . (1946)

Using the 3,000-mc 1-kw output of a magnetron, high-frequency energy is directed by a waveguide into the food to be defrosted, heated, or cooked. This unique device, called the Radarange, can cook a hamburger in 35 seconds and gingerbread will rise from batter to fluffy muffins in 29 seconds. The muffins however, will have no crust because the heat is generated in each molecule of the dough and does not have to be conducted from the surface to the center. Water content determines the reaction of each substance to the ultrahigh-frequency energy. Therefore, hot dogs can be cooked in paper wrappings and scrambled eggs can be prepared and served piping hot on a cold plate. **Raytheon Mfg. Co.**

The Transistor . . . (1948)

Like the vacuum tube, a transistor can serve as an amplifier or an oscillator, yet it contains no grid, plate, cathode,

(Continued on page 52A)

single phase protection

This low cost, ruggedly built unit gives you highest protection against high short circuit currents!

Mears fused circuit breakers meet the challenging need of industry for a unit that can perform with greater cost economy in applications where available power sources are large and high short circuit potential exists.

Only Mears fused circuit breakers give you the exclusive assurance of single phase protection! High rupture capacity, up to 200kA, 600 v A-c, 250 v D-c, is made possible through the use of H. R. C. fuses. Breaker trips after rupture of one or more fuses, eliminating the threat of costly equipment damage!

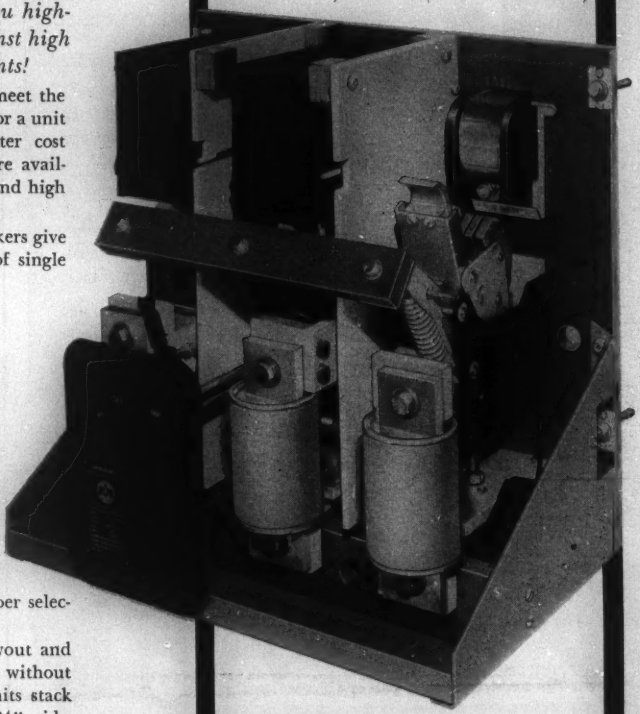
An outstanding feature of the Mears fused breaker is its unique ability to perform with the identical characteristics of a standard air circuit breaker when proper selection of fuses is made.

Available in fixed, semi-drawout and drawout mountings, with or without enclosures, these compact units stack four high. Only 22½" high, 24" wide. Simplified construction assures easy maintenance.

ARTWEL ELECTRIC, INC.
San Francisco, Calif.
F. M. BALLOU, P. E. & CO.
Ridgewood, N.J.
PAUL BERRY, INC.
Oklahoma City, Okla.
CHARLES E. COLBERT
Cleveland, Ohio
ELECTRICAL JOBBERS EQUIP. CO.
Minneapolis 15, Minn.
L. H. JONES COMPANY
Emmaus, Pa.
JAMES P. LAUGHLIN
Detroit 35, Mich.
H. G. LEHL
Oswego, Ore.
ROY PECK ASSOCIATES
Arcadia, Calif.
SLAYBAUGH-THOMPSON CO.
Denver, Colo.
WELDY ASSOCIATES, INC.
Chicago, Ill.
M. H. GOTTFRIED
Mexico 1, D.F., Mexico

MEARS new FUSED CIRCUIT BREAKER

Fused breaker shown is semi-drawout type—manually operated—1600 amp. frame size. (Cat. No. 210F-16P)



For complete information contact our representative or mail coupon today!

Mears Electric Circuit Breakers, Inc.
Swan Island, Portland 17, Oregon
Gentlemen: Please send me a copy of your Mears Low Voltage Circuit Breakers" Catalog.

Name
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electrical
enclosures
custom fabricated
by Kirk & Blum
• Control Desks and Consoles
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For industry, power plants and utilities, Kirk & Blum can produce any type of metal enclosure . . . quickly and economically.
Send your prints for prompt quotation.
50 YEARS OF SERVICE
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THE KIRK & BLUM MANUFACTURING CO. 3204 FORRER STREET, CINCINNATI 9, OHIO
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New Products, 1934-59

(*Continued from page 38A*)

glass envelope, or vacuum. Two point co tacts or "cat's whiskers" 0.002 inch apar called the "emitter" and "collector," a made to a germanium semiconductor. Th entire unit is housed on a small met cylinder less than 1 inch long. Amplific tion as high as 100 to 1 (20 decibels) possible at frequencies up to 10 mc. Be **Telephone Laboratories.**

Electroluminescent Lighting . . . (1951)

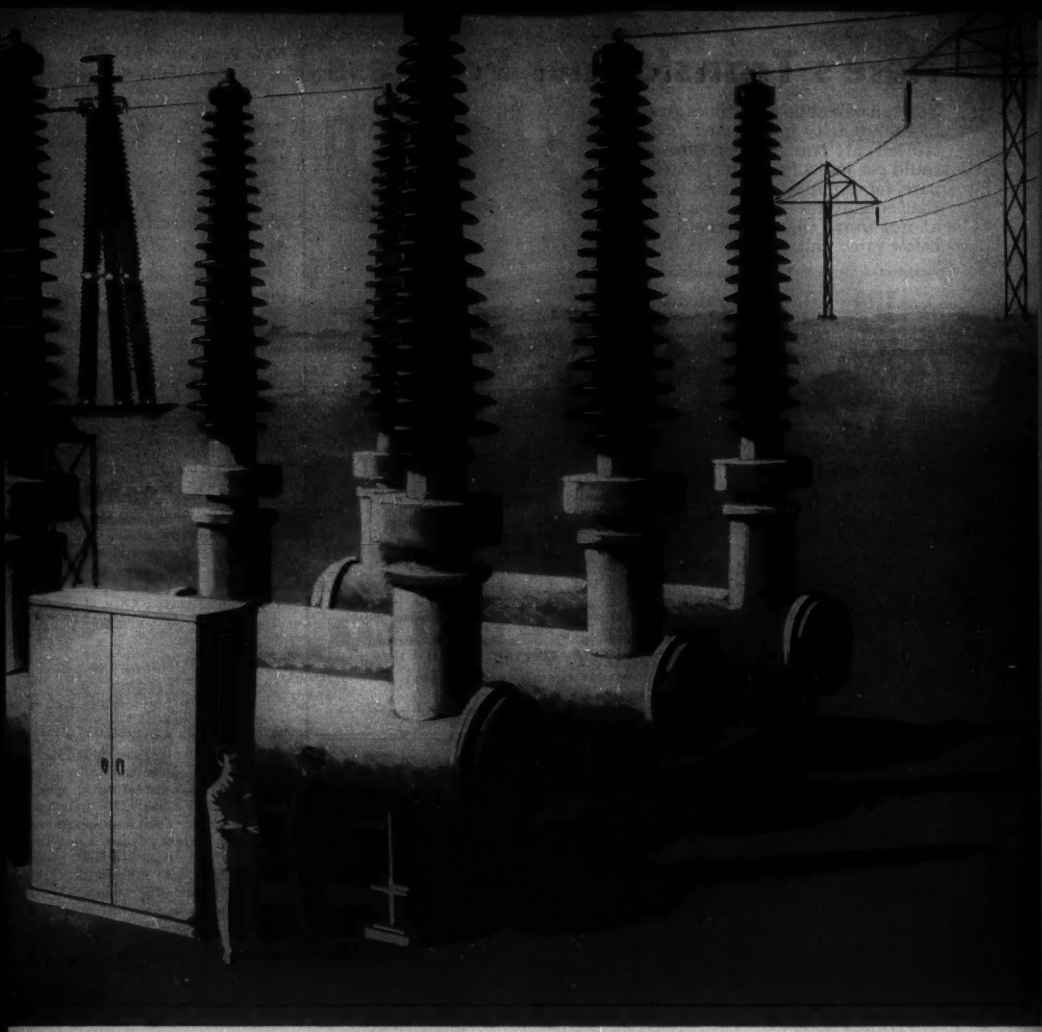
Transformation of electric energy d rectly into light can be made with th new development that discards the usu basic elements of a glowing filament gaseous discharge in a hermetically seale envelope. Composed of a thin film of pho phor dispersed in a dielectric and place between two conductive plates, one conductive glass for visibility, the materi is excited to luminescence in a fluctuatin electric field. The units will give sufficien light for many purposes at relatively lo a-c potentials and power frequencie although brilliance increases rapidly wit the increase in voltage and frequenc **Sylvania Electric Products, Inc.**

Solar Batteries . . . (1954)

An offshoot of the transistor, thes "solar batteries" convert the sun's energ directly into electricity. With a theoretic efficiency limit of 22%, the present ba tery's efficiency of 6% compares favorabl

with that of gasoline and steam engine in contrast with only 1% for other photo electric devices. Among some of the appli cations lending themselves to this uniqu energy converter are mobile radio-tele phones, sun-powered battery chargers fo

(*Continued on page 56A*)



of Colorado, Westinghouse began participating in a broad investigation of E-H-V transmission in the Rocky Mountains. This project includes measurement of corona and radio influence and exhaustive switching surge experiments. Conductor size and bundling effects, reduced insulation levels and economics of super-voltages are being studied as a further extension of Tidd tests at 10,000-ft altitudes under violent extremes of weather and temperature changes.

Spending millions to save utilities tens of millions

Building upon this field experience, and many successful commercial applications at 345 kv, apparatus has been further developed at modern test centers throughout Westinghouse—complete high-voltage, high-power test facilities allowing the development of equipment for 600-kv systems.

The concept of an E-H-V system was tackled 11 years ago. Westinghouse—and the industry—now knows that in seven years enough generating capacity will be added to power another America. To distribute this power economically—to distribute it at all—will require super-voltage systems. For 460-kv or 600-kv systems, Westinghouse is ready today to furnish equipment to do the job. J-97211

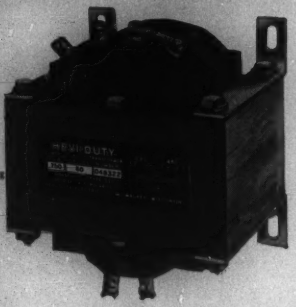
Because of the Westinghouse policy of plowing back earnings into the future of the electric utility industry, the challenge of 600-kv transmission systems has been met!

YOU CAN BE SURE...IF IT'S **Westinghouse**

WATCH "WESTINGHOUSE LUCILLE BALL-DESI ARNAZ SHOWS" CBS TV MONDAYS

Here's Transformer Progress

You can now obtain 2½ times greater inrush capacity from a *modern* control circuit transformer than you could get just a few years ago. Compare, for example, the inrush current that equally rated units can handle at not more than 5 percent drop below rated voltage.



1940 Ordinary transformer with non-interleaved windings — 400 Percent Inrush.

1945 Type SIO developed by Hevi-Duty with interleaved windings — 700 Percent Inrush

1957 New Type SZO with interleaved windings, plus other new design features developed by Hevi-Duty — 1,000 Percent Inrush

Yes, the story of transformer progress is still being written by Hevi-Duty.

Write for Bulletin 300 for full information on new Type SZO. Capacities from .050 to 5 KVA.

HEVI-DUTY ELECTRIC COMPANY

HEAT TREATING FURNACES HEVI-DUTY ELECTRIC EXCLUSIVELY
DRY TYPE TRANSFORMERS — CONSTANT CURRENT REGULATORS
MILWAUKEE 1, WISCONSIN

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MATERIALS HANDLING
Conference
(July 1958)

Sponsored by the AIEE Pittsburgh Section and Materials Handling Subcommittee, the proceedings of the AIEE Materials Handling Conference, held in Pittsburgh, Pa., May 19-20, 1958, have been made available in a 112-page publication.

Publication T-105 consists of nine papers and discussions on the following subjects:

1. bulk handling
2. low-voltage single-phase gantry crane
3. automatic freight
4. automatic warehousing
5. electronic weighing

Also included is an interesting address by A. C. Monteith, past president of the AIEE.

The price of publication T-105 is $4.00. Send to:

Order Department
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th St. • New York 18, N. Y.

New Products, 1934-59

(*Continued from page 52A*)

rural telephone systems, and interplan tary rocket probes. **Bell Telephone Lab ratories.**

Magnetic Tape Television Recorder . . . (1956)

It is now possible to record and sto "live" telecast programs on magnetic ta with picture quality said to be better tha current kinescope techniques. The ma problem that first had to be solved w recording frequencies as high as 4 mc a tape traveling at moderate speed pa the recording head. Sound magnetic r corders, dealing with frequencies up 15,000 cps, can achieve this with ta speeds as low as 7½ inches per secon To obtain a corresponding 4 mc respon would require tape speed of 2,000 inch per second! By recording the magne patterns transversely across the tape i stead of longitudinally and using a 4-he assembly rotating at very high speed, o full hour of video can now be record on a reel of magnetic tape only 14 inch in diameter. **Ampex Corp.**

Transatlantic Telephone by Cable . . . (1956)

Conversations via underwater cab are now a reality after 15 years of testi and development. Two cables, each o erating in opposite directions, are capab of handling 36 conversations at once, thr times the traffic normally handled ov radiotelephone. The deep-sea segment the system extends 2,250 miles betwe Newfoundland and Scotland. Repeat stations, located 40 miles apart, keep t signals constant and sharp. These r peaters had to be designed in such a w as to (1) pass easily through the shi laying gear without interruption, (2) wit stand pressures of at least 6,000 psi, an (3) operate without attention for at lea 20 years. **American Telephone & Te graph Co.**

Automatic Dispatching and Load Control . . . (1956)

The addition of a GEDA comput (Goodyear electronic differential analyze as an integral part of the Ohio Edison power system represents a milestone the application of computers to automat economic dispatching and load control o erations. The computer has three mod of operation—as a computing machine, an aid to the system dispatcher, and a system controller in conjunction wi conventional load frequency control equi ment. The device has eliminated mar scheduling chores and has relieved eng neering and operating personnel of tedio arithmetic tabulation work which was ne essary with the preparation of precalc lated dispatches. **Goodyear Aircraft Cor**

Individual circuit control. Install these new URELITE individually enclosed circuit breakers right near heavy loads or as local control devices for main trunk lines up to 600 volts. Main disconnect contacts visible through side window for extra safety. Now available with I-T-E K-LINE circuit breakers . . . world's most advanced. Pulldown handle action provides quick manual make for safety and long contact life. New, wide-range overcurrent trip device lets you increase breaker setting when the load increases. No parts to replace.

I-T-E Circuit Breaker Company I-2
1900 Hamilton St., Philadelphia 30, Pa.

- ☐ Power switching centers
- ☐ Molded case circuit breakers
- ☐ Metal-enclosed bus
- ☐ URELITE circuit breakers
- ☐ Other_____
- ☐ Metal-clad switchgear (4.16 and 13.8 kv)
- ☐ Secondary unit substations
- ☐ TRANFO-UNITS
- ☐ CORDON® circuit breakers

Name_____ Title_____

Company_____

Street_____

City_____ Zone_____ State_____

SEND COUPON OR WRITE

Get complete, up-to-date information on I-T-E equipment.

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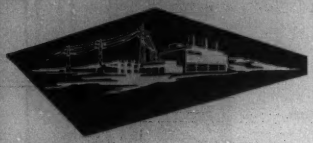
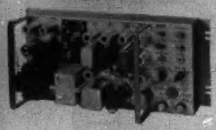
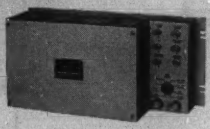
Telemeter
ANY VARIABLE
from Remote Points





MODEL 1025 Transmitter

MODEL 1090 Receiver



Accurate, Fast Acting, Frequency Type Telemeter for Transmission over Wire Lines, Microwave, and Power Line Carrier

Accurate HIGH-SPEED Continuous Telemeter for VOLTS AMPS WATTS VARS ETC.

•

Built-in Self-Calibrating Circuit

•

The Model 1025 Telemeter Transmitter converts DC mv from thermal converters, etc., to 10-30 cps which frequency modulates a built-in audio tone channel. AC 10 to 30 cps or relay outputs are also available. Receiver detects and demodulates transmitted signal, generating a DC mv for operation of recorders or indicating instruments. Up to 45 telemeters can be multiplexed.

Any communication link, including power line carrier, microwave or wire line may be used.

Over-all accuracy is 1% with a response speed of 1 second. Equipment features a built-in calibration circuit for 10% and 90% receiver check, and 10 cps and 30 cps transmitter check.

Any quantity which may be converted into a DC millivoltage or will operate a slidewire may be telemetered.

WE CAN HELP YOU

Our Applications Department is ready to assist you in your control, telemetering or communications problem. Phone DErfield 4-3100.

Write for Technical and Application Data.

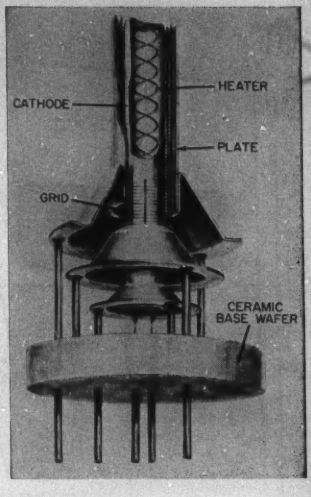
Radio Frequency
LABORATORIES, INC.
Boonton, New Jersey, U. S. A.

Circle 49 on reader service card.

Industrial Notes...

Minneapolis-Honeywell Minneapolis, Minn. . .

Up to eight independent jobs can be processed in this transistorized three address computer at the same time. Innovation of a traffic control allows the central processing unit to communicate simultaneously with 16 input–output components, thus eliminating bottlenecks caused by the relatively slow peripheral equipment. Another innovation is a multiprogram control that permits the processing unit to be used at top speed at all times by rationing time equally to each job being processed in parallel, i.e., 30,000 operations per second for one job, 15,000 for two, etc. Internal data transfer rate is 2 million decimal digits per second. Maximum decimal digit input or output is 96,000 per second. The Honeywell *800* can be expanded by adding modules to suit customer needs. Minneapolis-Honeywell Regulator Co., 2747 Fourth Ave., South, Minneapolis 8, Minn.



IBM White Plains, N. Y. . .

Arabic characters printed in magnetic ink which can be read by men or machines provide the key to this new check handling system. Each check is preprinted before issue with routing, transit, and account number data. Processing requires a proof-inscriber which writes dollar amounts in magnetic ink on each check and also prints endorsements and provides individual listings and accumulates control totals. Then the checks go to a sorter-reader that sorts the checks into desired sequences and reads the information for data input into a standard *407* accounting machine or a *650*, *705*, or *7070* computer. A utility inscriber is available to provide substitute documents with magnetic ink for processing through the banking equipment. International Business Machines Corp., Data Processing Div., 112 E. Post Rd., White Plains, N. Y.

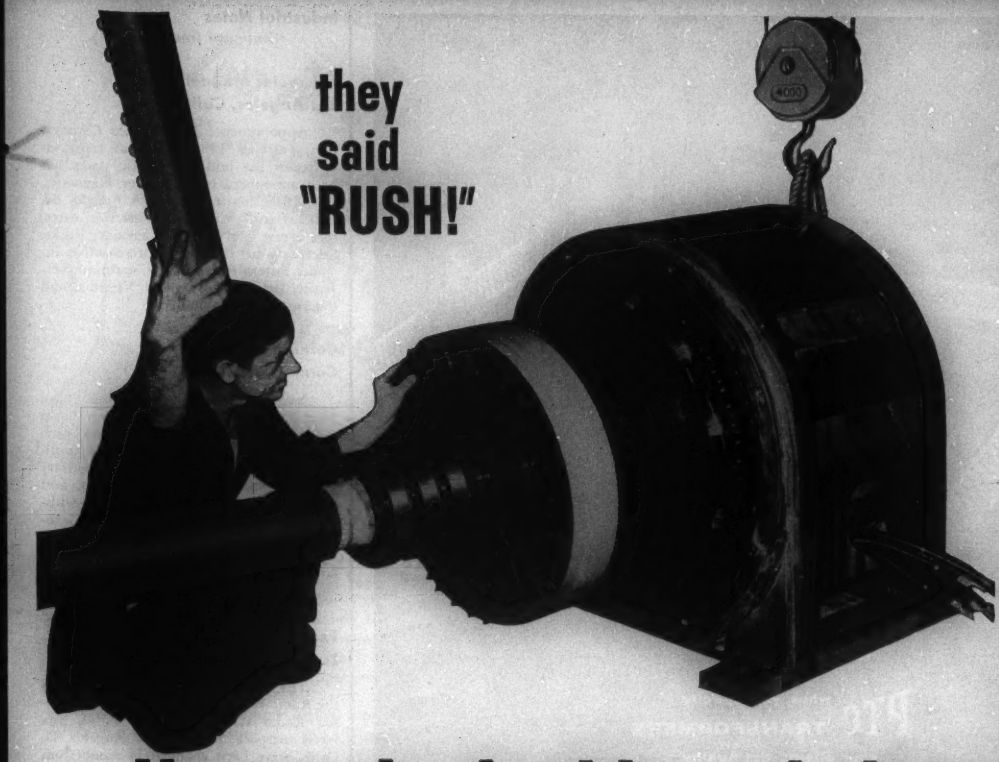
Radio Corporation of America New York, N. Y. . .

The Nuvistor, a tube design based on a new concept developed by the RCA Electron Tube Division, Harrison, N. J., makes possible thimble-size, more reliable and efficient, higher-performance, and more rugged electron tubes particularly suited for highly mechanized production. It is expected that tubes of the Nuvistor design will be useful in television sets, communication receivers, high-speed data-processing equipment, compact electronic equipment for jets, guided missiles, and military vehicles, as well as numerous other industrial and entertainment applications. Cylindrical symmetry and cantilever support of the electrodes provide a combination of high cathode efficiency and permits the use of accurate jigs for parts assembly. By the use of brazing instead of spot welding for the joining of materials, a potential source of failure is removed and residual strain in assembly is eliminated. There are no micas to fray under vibration or to interfere with high-temperature brazing and the exhaust processing of the tube. High-temperature processing eliminates many of the gases and impurities that are difficult to remove during manufacture of tubes of conventional design in which glass and mica limit the processing temperatures. Indexing lugs on the base of the Nuvistor permit safe and easy insertion into the tube socket and prevent damage to leads. Because the tubes have been degassed at high temperatures, they can be expected to operate at temperatures in excess of those permitted with conventional types.

Teletalent, Inc. New York, N. Y. . .

Department stores and supermarkets soon will be able to stage live displays in their windows by color closed-circuit television which is possible because of new engineering techniques, new knowledge of how to reduce costs of programs, and the advent of Eidophor (registered trade name), a Swiss-invented television projector. This device can throw a brilliant picture 20 by 15 feet in color, or 40 x 30 feet in black and white as sharp as a movie theater picture. This forecast is based on a study of merchandising methods by Teletalent, Inc., 274 Madison Ave., New York 16, N. Y.

(*Continued on page 74A*)



so National rebuilds and ships motor in 4½ days

FAILURE of this slip-ring induction motor threatened a shutdown of service. So the owner shipped the motor to National Electric Coil —to get it rebuilt fast and rebuilt right.

In just 4½ working days, here's what National did: *designed* and built both stator and rotor coils, rebabbitted the bearings, turned the slip rings, repaired stator laminations, rewound stator and rotor, dynamically balanced the rotor, performed complete checkout testing, crated, loaded and started the motor on its return trip!

For service when you need it, it's wise to have this responsible, competent organization on your electrical machinery team. Call or write for full information.

McGRAW EDISON

National Electric Coil

DIVISION OF McGRAW-EDISON COMPANY
COLUMBUS 16, OHIO

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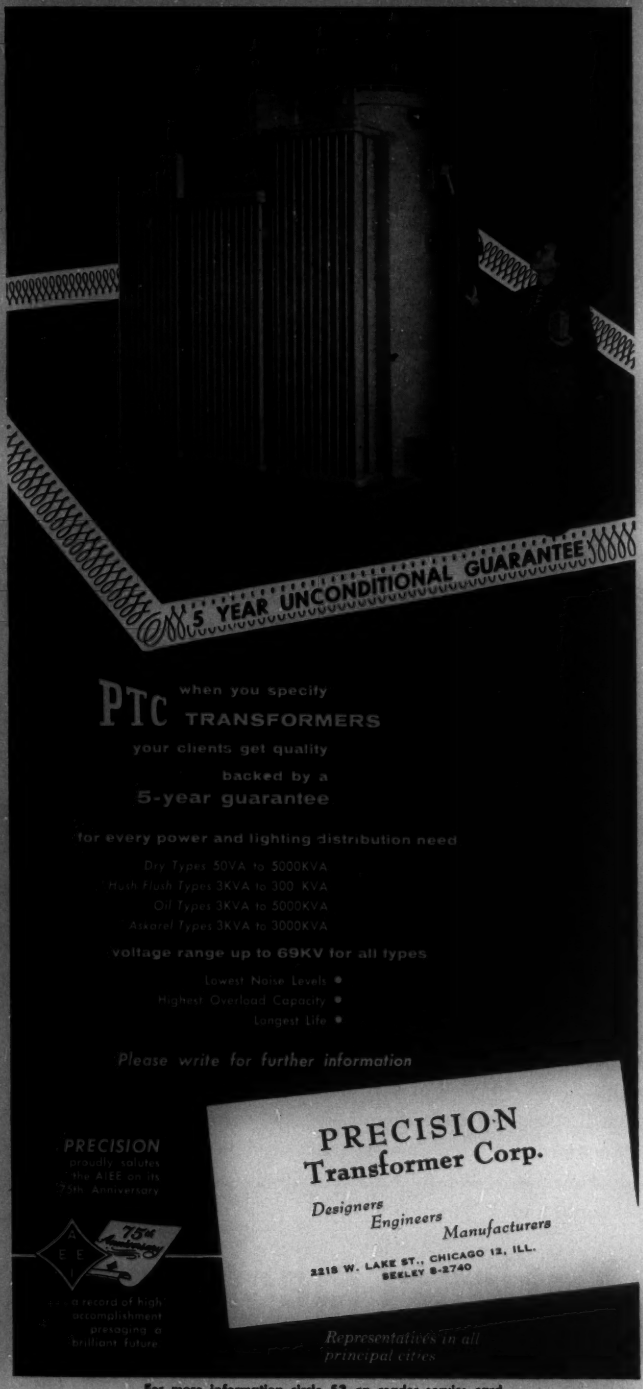
For more information circle 52 on reader service card.



For more information circle 53 on reader service card.

Industrial Notes

(*Continued from page 68A*)

Telemeter Magnetics, Inc.
Los Angeles, Calif. . .

Appointment of the Danco Corporation, Fairview Village, Pa., as representative in the middle Atlantic states has been announced by Telemeter Magnetics, Inc., 2245 Pontius Ave., Los Angeles 64, Calif. Danco will handle ferrite cores, core arrays, and computer memory stacks. Sales area of the new representative includes eastern Pennsylvania, southern New Jersey, Delaware, Maryland, Virginia, and the District of Columbia.

Corning Glass Works
Corning, N. Y. . .

New alumino-silicate glasses have been developed by Corning Glass Works for use in the high-temperature tube field. These glasses are particularly applicable for high performance military power tubes, magnetrons, klystrons, and traveling wave tubes. The glasses withstand processing (exhaust bakeout) temperatures in excess of 700C. They have excellent electrical properties, are resistant to adverse environmental conditions, and have a low helium permeability rate.

Thompson Ramo Wooldridge Inc.
Los Angeles, Calif. . .

The Denver Engineering Facilities of the Ramo-Wooldridge Division of Thompson Ramo Wooldridge Inc., P. O. Box 90534 Airport Station, Los Angeles 45, Calif., have been changed in name from Electronic Instrumentation Company to Denver Laboratories.

Martin-Baltimore
Baltimore, Md. . .

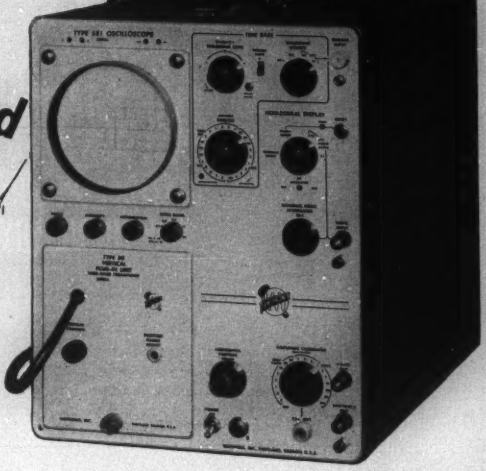
Breaking sharply with traditions of the aviation industry, Martin–Baltimore reorganized its 2,000-man engineering organization into separate task forces to develop and deliver manned vehicles and missiles and electronic systems. Replacing the previous single engineering division are two new organizations, Manned Vehicles and Missiles–Electronics. The Manned Vehicles Division will include manned aircraft of conventional and advanced types.

Tamar Electronics, Inc.
Santa Monica, Calif. . .

Acquisition of a 10,000-square-foot facility for expanded micro-wave-electronics research projects has been announced by this company located at 1805 Colorado Ave., Santa Monica. Engaged in both military and commercial projects, the company's chief hardware items include airborne transmission-line systems, transistorized radio remote control units, and microwave test equipment.

(*Continued on page 76A*)

Two New TEKTRONIX® Oscilloscopes each with 3.5-millimicrosecond risetime



TYPE 581

The new Tektronix Type 581 is a general-purpose oscilloscope with excellent transient response and high-speed sweeps. Risetime is 3.5 mμsec and sweep time is calibrated to 0.01 μsec/cm. Passband is dc to approximately 100 mc.

The vertical deflection system is designed for plug-in preamplifiers. A low-capacitance probe is an integral part of the Type 80 Plug-In Preamplifier, which provides a calibrated deflection factor of 0.1 v/cm. Sufficient signal delay is included in the main vertical amplifier to permit displaying the leading edge of the waveform under observation.

The wide sweep range of the Type 581 includes calibrated sweeps fast enough to take advantage of its risetime capabilities. Calibrated sweeps from 0.05 μsec/cm to 2 sec/cm are available in 24 steps, and a 5-x magnifier increases the calibrated range to 0.01 μsec/cm. Sweep time is continuously adjustable from 0.01 μsec/cm to 5 sec/cm. Versatile triggering includes amplitude-level control, and preset stability for operating convenience. Lockout-reset circuitry provides for one-shot sweep operation.

A new Tektronix cathode-ray tube with distributed-type vertical-deflection plates is used in the Type 581. 10-kv accelerating potential assures a bright trace, even at low sweep-repetition rates. An amplitude calibrator is also incorporated in the Type 581, with square-wave output from 0.2 mv to 100 v in 18 steps.

TYPE 585

The Tektronix Type 585 has, in addition to the identical general specifications of the Type 581, a second time base generator. This time-base generator, designated TIME BASE B, acts as a delay generator, providing a wide range of calibrated sweep delay. Two modes of sweep delay are available—triggered (delayed sweep is started after the delay period by the signal under observation), and conventional (delayed sweep is started at the end of the delay period by the delayed trigger). Calibrated sweep delay is continuously variable over the range of 1 μsec to 10 sec. Color-correlated controls eliminate confusion, making this new high-performance oscilloscope easy to operate.

PRICES

TYPE 581, without plug-in units **$1375**
TYPE 585, without plug-in units **$1675**
TYPE 80 Plug-In Preamplifier, with Probe **$ 150**

(Other plug-in preamplifiers are currently in development.)

Prices f.o.b. factory.

Tektronix, Inc.

P. O. Box 831 • Portland 7, Oregon
Phone CYpress 2-2611 • TWX-PD 311 • Cable: TEKTRONIX

TEKTRONIX FIELD OFFICES: Albertson, L. I., N.Y. • Albuquerque • Atlanta, Ga. • Bronxville, N.Y. • Buffalo • Cleveland • Dallas • Dayton • Elmwood Park, Ill. • Endwell, N.Y. • Houston Lathrup Village, Mich. • East Los Angeles • West Los Angeles • Minneapolis • Mission, Kansas Newtonville, Mass. • Orlando, Fla. • Palo Alto, Calif. • Philadelphia • Phoenix • San Diego St. Petersburg, Fla. • Syracuse • Towson, Md. • Union, N.J. • Washington, D.C. • Willowdale, Ont.

TEKTRONIX ENGINEERING REPRESENTATIVES: Hawthorne Electronics, Portland, Oregon., Seattle, Wash.; Hytronic Measurements, Denver, Colo., Salt Lake City, Utah.

Tektronix is represented in 20 overseas countries by qualified engineering organizations.

For more information circle 54 on reader service card.

*

GTC

*an effective, economical industrial communication system designed to provide swift and sure voice communications regardless of distance or surrounding noise conditions.

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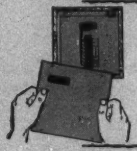
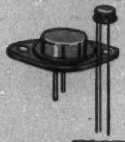
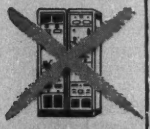


2. All amplifiers are "plug-in" contributing greatly to ease of installation and MAINTAINABILITY.



3. Transistors and rugged, industrial type components are used throughout. No vacuum tubes or "entertainment" type components of any kind are employed.



4. Central Control cabinet is eliminated thus reducing space requirement to a minimum.

5. ULTRA SIMPLE WIRING PLAN (no shielded cables) and UNITIZED EQUIPMENT with integral terminal facilities make for EASY LOW COST INSTALLATION and LATER EXPANSION.

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A SUBSIDIARY OF GILBERT ASSOCIATES, INC.
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For more information circle 55 on reader service card.

Industrial Notes

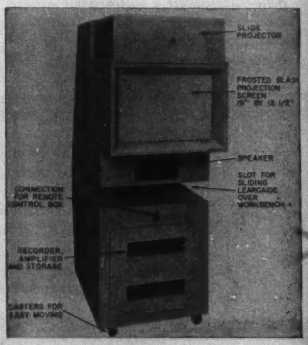
(*Continued from page 74A*)

Case Institute of Technology Cleveland, Ohio . . .

In order to improve long-distance communication techniques, engineers at Case Institute of Technology, University Circle, Cleveland 6, Ohio, are attempting to turn back split seconds of time. Their experiments depend on reversing the order of a series of signals sent over wires to improve the fidelity of transmission. A contract in the amount of $29,600 for a 1-year study of "Time Reversal Techniques" has been awarded to Dr. H. W. Mergler, Assistant Professor of Mechanical Engineering by the Rome Air Development Center. Under his direction the scientists will attempt to implement the theory that signals transmitted over long disances, if reversed in direction of flow at the midpoint of the distance from transmitter to receiver, will retain their fidelity over the entire route of transmission.

Lear, Inc. Grand Rapids, Mich. . .

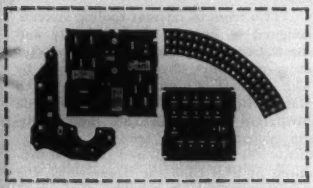
Lengthy training periods for the most intricate and complex assembly work can be cut by as much as 50% with the Learoaide, a visual-audio training unit, that synchronizes a color slide projector with a customized tape recorder providing assembly instruction presentations. Trainees determine their own learning pace through any step-by-step assembly process by controlling sequences



with a stop-start-repeat feature incorporated in the Learoaide. Reduced rework, scrap, and job complication, and greater job uniformity result during the necessary training period. When a change in assembly procedure is required, it is accomplished simply by substituting a new slide and rerecording the corresponding part of the tape. Write J. A. Andrews, Lear, Inc., P. O. Box 688, Grand Rapids, Mich.

(*Continued on page 80A*)

LET SPAULDING GIVE YOU A HAND WITH YOUR TERMINAL BOARD PROBLEMS



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Industrial Notes

(*Continued from page 76A*)

Burndy Corp. Norwalk, Conn. . .

This company has contracted to acquire H. H. Buggie, Inc., of Toledo, Ohio. The company, manufacturer of electrical connectors thus broadens an already substantial line of connectors for the electronics market currently manufactured and sold by its Omaton Division. H. H. Buggie Inc., an established company with about 250 employees, manufactures a high quality line of miniature disconnects, printed circuit connectors, rack and panel connectors, coaxial and triaxial connectors, and radar pulse cable assemblies. These lines consist of some 6,000 items, many of them variations of basic design concepts originated by the Buggie company.

Sylvania Electric Products Inc. New York, N. Y. . .

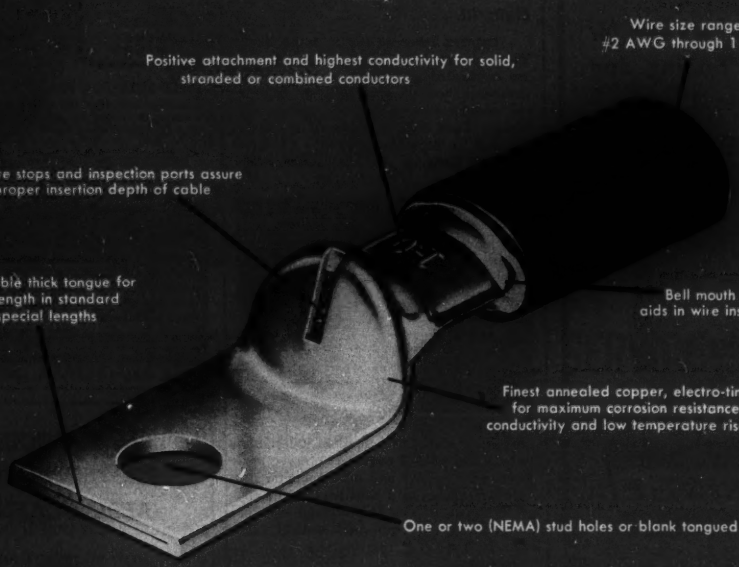
The share owners of Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y., have voted approval of the merger of Sylvania into General Telephone Corp.; the share owners of General Telephone also approved the merger and voted a new corporate name, General Telephone & Electronics Corp. D. C. Power, president of General Telephone, will become Chairman of the Board and chief executive officer of the combined corporation, while D. G. Mitchell will become President, also continuing as Chairman of Sylvania. Sylvania will continue to operate as a separate company, wholly owned by General Telephone & Electronics Corp.

The Garrett Corp. Los Angeles, Calif. . .

Two types of cryostat cooling systems, designed to improve the sensitivity and spectral response of infrared and detector units on missiles, have been developed by The Garrett Corporation's AiResearch Manufacturing Division, 9851 Sepulveda Blvd., Los Angeles 45, Calif. Specifically, the systems cool the semiconductor elements which detect infrared radiation produced by heat from the target which the missile is seeking. It has been determined that, for maximum response to this radiation, the semiconductors must be maintained at an extremely low temperature. The AiResearch systems are capable of maintaining the temperature at a steady —300 F. One system uses liquid nitrogen at low pressure with a special Dewar flask. Another method uses nitrogen gas contained at high pressure—3,000 to 5,000 psig.

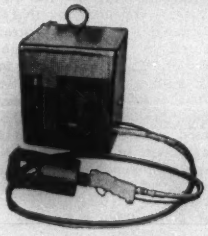
(*Continued on page 86A*)

KING SIZE STRENGTH AND ECONOMY WITH AMPOWER


Wire size range from #2 AWG through 1125 MCM
Positive attachment and highest conductivity for solid, stranded or combined conductors
Wire stops and inspection ports assure proper insertion depth of cable
Double thick tongue for double strength in standard or special lengths
Bell mouth opening aids in wire insertions
Finest annealed copper, electro-tinned for maximum corrosion resistance, highest conductivity and low temperature rise
One or two (NEMA) stud holes or blank tongued

for solid, stranded or combined conductors from #2 AWG to 1125 MCM

Matching Dyna-Crimp precision tool is an electrically operated, hydraulic tool which combines the mobility features of a hand tool with the strength and precision of a bench mounted press. The tensile strength of the formulated "C" crimp which Dyna-Crimp creates approaches that of the cable tensile strength.



AMPOWER Terminals and Splices plus Dyna-Crimp tooling are a matched team that give you the finest finished attachments you can buy . . . at the lowest total installed cost. For more information, request our new AMPOWER brochure . . .

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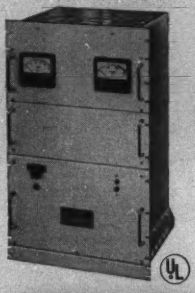

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Write For Bulletin AC-58-A

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3410 W. 67th Street
Los Angeles 43, Calif.

Circle 67 on reader service card.

Industrial Notes

(Continued from page 80A)

Hoffman Electronics Corp. Los Angeles, Calif. . .

Headquarters for the Hoffman Science Center, newly formed division of Hoffman Electronics Corporation, have been established at 415 E. Montecito St., Santa Barbara, Calif., pending construction of a permanent facility. The division is to be devoted exclusively to research.

Elgin Metalformers Corp. Elgin, Ill. . .

Captive firings of the U. S. Air Force Thor intermediate range ballistic missile are controlled and data recorded by instruments housed in EMCOR cabinets at the Douglas Aircraft Co., Inc., Sacramento Missiles Field Base, Nimbus, Calif. Manufactured by Elgin Metalformers Corporation, 630 Congdon Ave., the cabinets are

part of an elaborate test facility designed to let scientists and engineers observe performance of engine and other components without expending a missile. Human engineering features of the modular cabinet design bring all equipment within easy reach and sight of the operator.

Eitel-McCullough, Inc. San Carlos, Calif. . .

An extensive military and commercial communications system linking continental members of the North Atlantic Treaty Organization (NATO) will be powered by Eimac klystrons manufactured by Eimac klystrons manufactured by Eitel-McCullough, Inc., San Carlos, Calif. Contracts in excess of $1 million have been received by Eimac from two NATO prime contractors who have specified that Eimac klystrons will be used exclusively as 1- and 10-kw power amplifiers in the strategic NATO tropospheric communication system in Europe.

P. R. Mallory & Co. Inc. Indianapolis, Ind. . .

A subsidiary company, P. R. Mallory International Inc., has been formed for the purpose of managing Mallory's foreign activities and interests. Offices of the new company are located at 41 E. 42nd St., New York, N. Y., and 3029 Washington St., Indianapolis, Ind.

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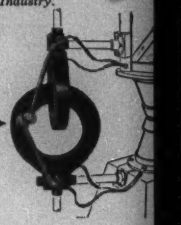

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▲ **Circle 68 on reader service card.**

PERFORMANCE AND PROTECTION OF AERIAL CABLES

February 1958

This informative 44-page publication consists of six transactions and conference papers with discussions and closures on cable insulations, various practices in the installation of these cables, and the results of actual field tests to determine some of the phenomena which have taken place.

The papers were presented at the 1957 Summer General Meeting of the American Institute of Electrical Engineers, Montreal, Que., Canada, June 24-28, 1957.

Publication S-102 is available for $2.50 from the Order Department.

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Environmental Test Facility Technical Bulletin . . .

Facilities and functions of an electronic and electromechanical environmental test facility are explained and illustrated in a 6-page technical bulletin released by **BJ Electronics, Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.**

Voltage Regulator Bulletin . . .

Described in a 2-page technical data bulletin is the new 30-finger *4K* REGOHM voltage regulator. The unit is designed to handle the heavy currents encountered in battery charger applications; and for exciter and main field generator control. Small sized, lightweight, it can regulate sets up to 600 kva, 1,800 rpm. **Electric Regulator Corp., Pearl St., Norwalk, Conn.**

Silicon Rectifier Handbook . . .

A 2-color, 48-page silicon rectifier handbook containing electrical ratings, performance data, and dimensional drawings for every type of silicon rectifier, designated as catalog No. 69, also deals with silicon rectifier theory of operation, manufacture, characteristics, and application. **Sarkes Tarzian, Inc., Rectifier Division, Bloomington, Ind.**

Selenium Photocell Catalog . . .

An 8-page catalog entitled "Selenium Photovoltaic Cells," describes over 25 standard selenium cell types, including cell structure and operation, performance characteristics, output-current curves, and typical applications in electrical and industrial engineering, chemistry, photography, photometry, and medicine. Request Bulletin *PC-649A*, **International Rectifier Corporation, 1521 E. Grand Ave., El Segundo, Calif.**

Extinguishing Systems Brochure . . .

Covered in a 28-page brochure are nine major brands of interior fire extinguishing systems, portable extinguishers, cabinets, and other inside fire control products. Form No. *S-62* can be obtained by writing **The Fyr-Fyter Co., Customer Service Department, 221 Crane St., Dayton 1, Ohio.**

Tape Temperature Limits Guide . . .

A general guide to the upper temperature limits of electrical tapes is provided in a 4-page brochure recently released by **Minnesota Mining and Manufacturing Co., 900 Bush Ave., St. Paul, Minn.**

Bearing Lubrication Manual . . .

Lubrication of miniature instrument bearings is the subject of a manual recently issued which supplies data and information of the various types and brands of oils and greases available to bearing designers and users. **Miniature Precision Bearings, Inc., Precision Park, Keene, N. H.**

Closed-Circuit TV Equipment Bulletin . . .

An 8-page illustrated bulletin, (Catalog No. *6-103*), describing their complete line of closed-circuit television equipment is now available from the KIN TEL Division, Cohu Electronics, Inc., 5725 Kearny Villa Rd., San Diego, Calif.

Synchro Coupling Problems . . .

Problems associated with coupling a synchro under test to a precision angular divider are discussed in a technical bulletin. Angular and parallel misalignments are treated in a unique manner to produce a rotational standard with essentially zero transmission error. **Theta Instrument Corp., 48 Pine St., East Paterson, N. J.**

Motor and Blower Catalog . . .

This 16-page catalog describes subfractional horsepower motors and blowers with photographs and detailed diagrams of 2- and 4-pole induction motors, capacitor motors, universal motors, gearmotors, single and double blowers, and blower heater units. Convenient tables provide technical data on horsepower, voltage ratings, load speed, rotation, and mountings. Performance curves are charted to indicate speed and torque. **Heinze Electric Co., 685 Lawrence St., Lowell, Mass.**

Automated Checkout Booklet . . .

Several novel approaches have recently been developed to solve the problem of maintaining complex military electronic equipment in a state of combat readiness. The technique described in the booklet "14 Men in a Box" utilizes a series of portable "black boxes" for performing a programmed sequence of automatic checkout procedures. To initiate a test, the operator simply pushes a button on the panel; test results are shown by green and red "GO-NO GO" lamps. Each black box is designed to test a specific equipment or, in the case of large systems, a specific unit. **Checkmate Automatic Test Equipment Co., a Division of CGS Laboratories, Inc., Ridgefield, Conn.**

(Continued on page 102A)

C37.12	Guide Specifications for A-C Power Circuit Breakers (Aug. 1952)	.60
C37.13	Low-Voltage Air Circuit Breakers (including Application Guide) (Aug. 1954)	.80
C37.14	Test Code for Low-Voltage Air Circuit Breakers (Aug. 1954)	.50
C37.15	Rated Control Voltages & Their Ranges for Low-Voltage Air Circuit Breakers (Aug. 1954)	.30
C37.16	Schedule of Preferred Ratings for Alternating- and Direct-Current Low-Voltage Air Circuit Breakers (Aug. 1958)	.40
C37.17	Preferred Pick-Up Calibrations and Trip Delay Settings for Alternating-Current Low-Voltage Air Circuit Breakers (10-56)	.30
C37.20	Switchgear Assemblies and Metal-Enclosed Bus (AIEE No. 27) (Jan. 1955)	.60
C39.1	Electric Indicating Instruments (Panel, Switchboard and Portable Instruments) (Aug. 1955)	2.00
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C42 series *American Standard Definitions of Electrical Terms*

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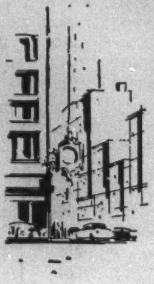

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